Enterprise Accomplishments

This section of the Annual Progress Report highlights a number of major accomplishments made by the teams of scientists and engineers from NASA, industry, the FAA, and academia over the past year. The accomplishments are grouped by the goals presented in Part I of this report. It is against these goals that we will begin measuring the progress of our technology programs and our partnerships.

Over the past several months, the Enterprise has been developing national plans to ensure that our technology programs address the key challenges of the goals and are coordinated with the efforts of the FAA, industry, and DoD. These plans will be our "roadmaps" for achieving the outcomes envisioned in the Ten Goals.

Roadmaps

A senior-level team was assembled for each strategic goal with members from NASA, industry, and, as appropriate, the FAA and DoD. The teams were charged with developing comprehensive roadmaps, which would become our blueprint for program development and budgeting. As part of those activities, the full portfolio of the Enterprise's programs and research activities were carefully examined to assess their contributions to the Ten Goals.

The strategic roadmaps have been completed, each describing the needed technology objectives and how they fit programmatically within 10- and 25-year timeframes. The roadmaps are currently being reviewed by our partners, customers, and stakeholders, and will be featured as part of next year's progress report. Through the detailed planning and projections built into each roadmap, we have created a quantifiable way of measuring our progress against a "yardstick" that is 25 years long. The Enterprise is committed to developing technologies that address national needs and providing these technologies at the right time and with sufficient maturity to maximize the likelihood of their application.

Accomplishments

The accomplishments presented in this section are products of ongoing research being performed at the NASA Centers. While many of the accomplishments were achieved in laboratories, a large number of them were performed in real-world environments, such as at airports and on icy runways in Canada.

Each goal begins with an introductory outline of the research scope, followed by the accomplishments contributing to that goal. In many cases an accomplishment supports more than one goal; however, it is listed with the goal that is the primary beneficiary. For example, a new structural technology grouped in the affordability goal, because of its manufacturing advantages, also contributes to vehicle safety, because of its structural properties, and to environmental compatibility, because lighter weight constructions result in lower fuel consumption and thus lower emissions.

The following accomplishments represent a range of technical maturity, from basic research and fundamental discoveries to technology demonstrations in flight research programs. In the process of developing technology, each is important. Scientists and engineers must prove the feasibility and viability of new tools, operational concepts, and technology solutions each step of the way.

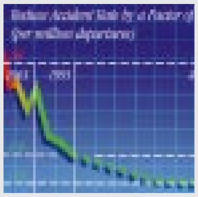
A response card is included in this report for comments or questions about any of the material in this report, or your comments in general. We welcome your feedback.

Pillar One: Global Civil Aviation

Prior to 1974, large commercial transport manufacturing was the domain of the United States, which held more than 90 percent of the world market share. Today, that market consists of more than 12,000 airplanes in commercial service, and the U.S. share has dropped significantly. Projections linked to world economic growth suggest that the demand for air travel will triple over the next 20 years, requiring thousands of new aircraft.

To preserve our Nation's economic health and the welfare of the traveling public, NASA must provide technology advances for safer, more environmentally compatible, and more affordable air travel.

Goal 1: Aviation Safety



Our society is highly dependent on air transportation. Great strides have been made over the last 40 years to make flying the safest of all the major modes of transportation. If air traffic triples as predicted within the next 20 years, even today's low rate of less than two accidents per million flights will be unacceptable. Dramatic steps, through joint FAA and NASA research, will assure unquestioned safety for the traveling public.

Enabling Technology Goal: Reduce the aircraft accident rate by a factor of five within 10 years, and by a factor of 10 within 25 years.

Slippery Runways Will Not Slow Airports Down

Ice or snow on a runway was a factor in approximately 30 airplane accidents between 1983 and 1995. Inaccurate, incomplete, or confusing runway surface information was also a contributing factor in a number of cases in which airliners were dangerously slow in reaching liftoff speed because of the effect of snow, ice, or rain. A 5-year joint NASA, FAA, and Transport Canada research effort has been under way to focus on proving technology concepts for a better understanding of runway friction, improved tire designs, better chemical treatments for snow and ice, and new types of runway surfaces that minimize bad weather effects.

In a recent major accomplishment, the research team developed an international runway friction indexing method. To develop the index, researchers performed braking tests with ground friction measuring vehicles and research aircraft on a variety of dry, wet, snowy, and icy runway conditions. The next step of this research will focus on relating the index to different aircraft types and sizes. The index, which is anticipated to become an international standard for assessing runway conditions, will facilitate safe takeoff and landing decisions based on readings taken by a ground-friction measurement vehicle on the same runway.

"The index will be a single, accurate, and easy-to-use tool to help both pilots and airport operators worldwide quickly assess winter runway conditions," said Thomas Yager, lead engineer from NASA's

The NASA 737 research airplane is conducting braking tests in Canada to investigate runway friction during snow and ice conditions.

Langley Research Center. This index will help prevent accidents and reduce unnecessary delays by providing airlines the necessary information to operate safely under adverse weather conditions. The FAA is expected to approve the index for use by the airlines in 1998.

Protecting Passengers and the Environment

Inventors show the new "food-grade" anti-icing fluid (held in beaker), which provides a long-lasting barrier to ice and does not harm the environment.

An anti-icing fluid developed at Ames Research Center promises to make flying safer without introducing dangerous chemicals into the environment. The patented new fluid is so environmentally safe that it has been referred to as "food grade." The new fluid contains propylene glycol, which is safe, instead of ingredients such as ethylene glycol and additives that can sicken or kill water life, animals, and human beings.

In some respects, it even works better than current anti-icing fluids. The environmentally friendly fluid "grabs" onto an airplane's surface more effectively than current fluids when the plane is at rest, providing a long-lasting barrier against ice buildup.

Worldwide, about one-half billion gallons of aircraft de-icing fluid are used annually. Much of this could be replaced with the new fluid, thus reducing environmental costs to government and industry, and ultimately to taxpayers for cleaning toxic anti-icing fluids from the environment.

The new anti-icing fluid has many more potential uses, such as on bridges, streets, runways, and railroad switches, and even around homes for roofs and sidewalks. Because the fluid is nonconductive and neutral (neither an acid nor a base), roadways and bridges treated with the fluid will avoid corrosion of the rebar and other steel and concrete parts. Similarly, vehicles will avoid the body corrosion typically associated with the use of road salt. Power companies are interested in using a thicker, grease-like version of the fluid to protect substation electrical components and power cables from ice. Interest in commercial distribution of this product could potentially make it available next year.

Guest Pilots Fly With Ice

The study of tailplane ice formation (inset) leads to better understanding of tailplane stall conditions and effective recovery procedures.

Between 1990 and 1996, the number of accidents related to icing, both fatal and non-fatal, accounted for over 11 percent of all weather-related accidents. The NASA/FAA Tailplane Icing Program (TIP) recently completed its final stage of flight testing by providing demonstration flights through a Guest Pilot Workshop. The TIP was a four-year research program that utilized a combination of facilities that included NASA's Icing Research Tunnel and DeHavilland DHC-6 Twin Otter Icing Research Aircraft at Lewis Research Center, and Ohio State University's Low Speed Wind Tunnel.

This icing research program was the most comprehensive and complete investigation of its kind. The objectives were to improve understanding of aircraft aerodynamics and performance under iced tailplane conditions, and to develop training aides and design tools to expand the awareness of the safety threat called Ice Contaminated Tailplane Stall.

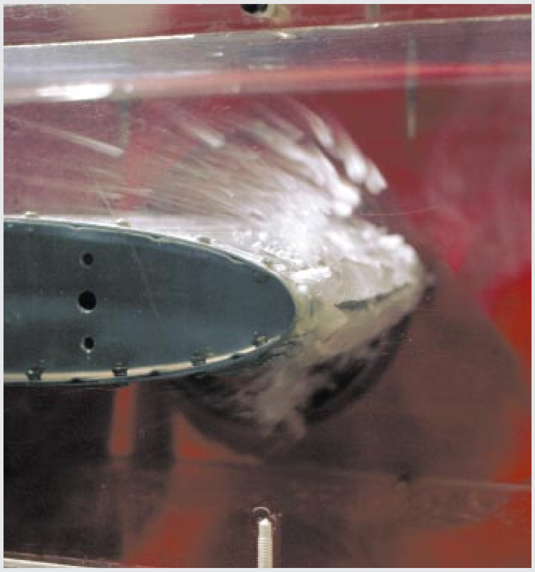
The Tailplane Icing Program's major accomplishments were: (1) developing a comprehensive database on tailplane aeroperformance; (2) identifying dominant drivers leading to tailplane stall; (3) demonstrating effective tailplane stall recovery procedures; and (4) providing in-flight demonstrations to guest pilots. Future plans include developing a pilot training video, and a sequel to the Guest Pilot Workshop to provide the safety training experience to an increased number of pilots.

In total, 15 guest pilots and engineers had the opportunity to fly the Twin Otter and witness first-hand the unique flying qualities of an aircraft with an ice-contaminated tailplane. Feedback from the guest pilots has been very positive. Learjet's adoption of the NASA-developed test method as part of their test procedures is an illustration of the quality and relevance of NASA's research.

Lightweight Zapper a "Heavyweight" With Ice

An innovative NASA ice removal system will be included with the first new general aviation aircraft to be introduced in the United States in 15 years. The lightweight, patented device will "zap" dangerous ice from wings and other aircraft parts during flight. Even in warm climates, aircraft icing can be a problem at higher altitudes where temperatures are cold. Officially known as the Electro-Expulsive Separation System, the ice zapper uses one-thousandth the power and is one-tenth the weight of electrothermal ice removal systems used today.

The system pulverizes ice into small particles and removes layers of ice as thin as frost or as thick as an inch of glaze. It uses a powerful electronic photoflash-like power supply combined with a thin copper ribbon that looks like a belt flattened on itself and embedded in a rubbery plastic. The looped, flattened copper ribbons are bonded to wings, engine inlets and other airplane parts where ice can form. In less than a millisecond, the system sends bursts of high-current electricity through the two parallel layers of copper ribbon. The resultant magnetic fields suddenly repel each other.

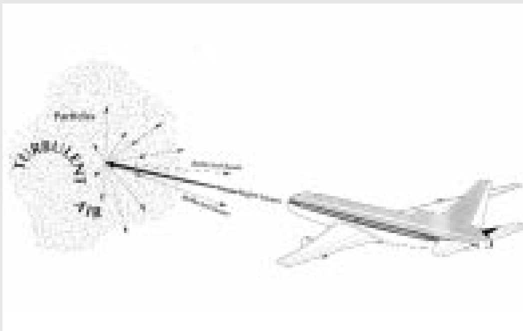


This high-speed photo captures ice as it is "zapped" from a wing surface.

The upper ribbon jumps less than twenty-thousandth of an inch, causing a high acceleration. The motion breaks the ice bond, shatters the ice into table-salt-sized particles, and expels them from the airplane's surface. The system can run continually during flight, pulsing once or twice a minute, to keep airplane surfaces ice free. The system's overlapping copper ribbon prevents electrical interference.

In 1995, NASA licensed the ice zapper to Ice Management Systems, Inc., Temecula, California, for development and marketing. Ice Management recently agreed to develop the system for Lancair Inc., Bend, Oregon. The ice removal system was tested with the Lancair IV aircraft and will be available in the fall of 1998 with Lancair's new Columbia 300, a four-seat, general aviation airplane. The ice zapper could greatly improve aircraft flight safety.

Laser Technology Detects Dangerous Turbulence



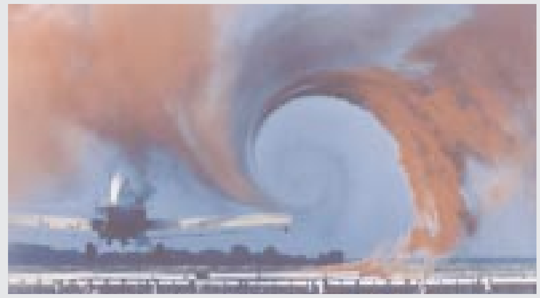
Detecting nonvisible turbulence with a laser light beam will provide pilots valuable seconds for warning crew and passengers and taking safety precautions.

Turbulent air is a weather phenomenon that can be invisible both to the eye and to radar, yet it is the leading cause of inflight injuries to the flying public. In the spring of 1998, the Dryden Flight Research Center completed its first series of flight tests of a sensor to detect clear air turbulence, with promising results. The sensor device, called Airborne Coherent LIDAR for Advanced In-flight Measurement (ACLAIM), was designed and built for NASA by Coherent Technologies of Lafayette, Colorado.

ACLAIM relies on a form of laser technology called Light Detection and Ranging (LIDAR), to detect changing velocities of tiny particles in turbulent air. In the first tests, the experiment team located turbulent conditions and took measurements of those conditions, before flying through the disturbed air. By exploring the relationship between the laser-measured turbulence characteristics and the actual turbulence experienced by the aircraft, researchers are constructing a data base to help learn more about accurately detecting and forecasting turbulence.

The ACLAIM sensor, which could alert pilots of turbulence 20 seconds to 1 minute away, would allow pilots valuable time to take safety precautions and provide warnings to the crew and passengers. Future tests are slated to add to the turbulence data base and to fine-tune the sensor for better measurements.

Studying Airplane Wakes to Design a Smoother Ride



The study to improve modeling of trailing vortices will lead to better aircraft designs and airliner spacing during takeoff and landing.

The generation of trailing vortices (invisible, thin, tornado-like cones) off aircraft wing tips is a consideration for new aircraft designs. During heavy traffic around airports, these vortices are potentially hazardous because they can persist for miles following an aircraft. These wing tip vortices and their breakdown are difficult to predict.

In 1997, the Langley Research Center conducted a pioneering study to improve the modeling of vortex flows and vortex breakdown. The results showed that the class of models known as Reynolds-stress turbulence models gave much more accurate calculations than other models. These models yielded significantly better predictions of the breakdown location, and they offer increased design confidence and the potential to reduce the development time for aircraft.

Designing Cockpits for Safety

Research pilot tests new "human-centered" cockpit design.

More than 70 percent of all aviation accidents have been attributed to human error. Because of the unpredictable nature of flying, human beings, not computers, still make the critical flight decisions. To make the greatest technical strides in aviation safety, flight decks must be designed to help safeguard against human error while still leaving the pilots in control.

Although cockpit displays, control yokes, seats, and cabins have improved over the years, the designs did not necessarily evolve with pilots in mind. Researchers at the Langley Research Center are taking the first steps at designing an "error-proof flight deck" concept that is based on "human-centered" design. The research focuses on developing methods for identifying and controlling factors that lead to human error. Implementing such a design will allow for human error without jeopardizing the safety and efficiency of a flight mission.

The human-centered flight deck will use advanced measurement technologies and novel pilot-to-plane interfaces to enhance the capabilities of the crew. These technologies could include imaging systems that see through fog and darkness, biofeedback systems to monitor stress and fatigue, onboard memory that reduces the mental workload of the pilot, and computerized flight management systems that question unusual flight coordinates. Researchers also envision a design that focuses on increasing pilot awareness and involvement without increasing workload. In future work, researchers will test these human-centered technologies to determine how effective they are at reducing human error.

Combating Pilot Fatigue Can Be a Science

The National Transportation Safety Board has investigated accidents in every mode of transportation in which the effects of fatigue have been found to be a causal or contributing factor. NASA began studying pilot fatigue after data obtained from the Aviation Safety Reporting System (ASRS) also revealed concerns about the issue.

The ASRS receives numerous reports from pilots of commuter aircraft alleging that fatigue induced by long duty schedules, compounded by inadequate rest, is often a primary factor in aviation safety incidents. Since the Fatigue Countermeasures Program began, NASA has conducted extensive research, including field studies, to document the effects of fatigue during air transport operations and to develop countermeasures.

Boeing 747 pilot participating in NASA's human factors research studying ways to combat pilot fatigue.

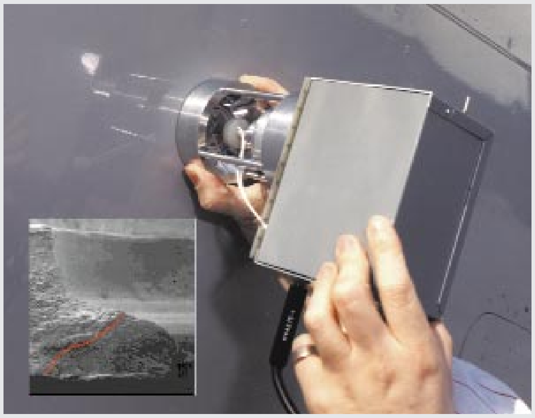
When the Ames Research Center started the program in 1980, there was little information available about the physiology of sleep deprivation and fatigue. In conjunction with their research on the physiological factors associated with sleep loss and circadian disruption that underlie fatigue, the scientists have developed a training course that shows pilots how to combat the adverse effects of fatigue. The training covers such topics as sleep, circadian rhythms, misconceptions about fatigue, and recommended ways to offset it.

Pilots Train in the "Real World"

Commercial pilots do not often face flying during extreme conditions, such as icing, wake vortex, or wind shear encounters. However, it is during these unusual circumstances that many accidents occur. Accurate flight simulation training to ensure that pilots are prepared for these extreme conditions is essential to increasing safety for the flying public.

To improve pilot training, NASA researchers have developed methods to accurately reproduce in the flight simulator what the pilot would experience in the actual aircraft. Wind tunnel tests were

The realistic flight simulator cockpit supports research to improve pilot training for extreme flying conditions.



The NASA-developed sensor allows detection of structural damage, capable of locating cracks (inset) 70 percent smaller than cracks detected using current devices.

conducted and the data analyzed so that researchers could mathematically model the aerodynamic forces and develop software programs that would recreate these forces for the realistic simulations.

In the future, researchers will use these mathematical models to develop new control laws to help increase the stability of the aircraft under these extreme aerodynamic forces. Increased stability and performance will enable safer and more efficient operation of commercial transports and high-performance aircraft.

Planes Can Avoid Early Retirement

Aircraft are typically designed for 25 to 30 years of operation. In 1990, approximately 46 percent of the U.S. commercial aircraft fleet was more than 15 years old, and 26 percent was more than 20 years old. By the year 2000, the number of aircraft more than 20 years old is expected to double.

To help ensure continued safe operation of the U.S. commercial aircraft fleet, NASA is developing advanced technologies that U.S. airlines and aircraft manufacturers may use to reliably and economically inspect the growing number of "high-time" airplanes. As part of this effort, the Langley Research Center has developed a breakthrough technology for rapidly and reliably detecting fatigue damage—typically microscopic cracks in aircraft structures—caused primarily by the repeated stresses experienced during the takeoff and landing cycles. Such cracks can cause potentially catastrophic failures.

The technology has been integrated into a small, handheld instrument called a probe, which is capable of detecting cracks that are 70 percent smaller than cracks detected with current techniques. Using eddy currents to detect cracks caused by fatigue, the probe's 90-percent certainty rate will allow airlines increased confidence in the accuracy of nondestructive evaluation (NDE) inspections. It has been field-tested with aircraft manufacturers and the FAA NDE Validation Center.

The results show that the cost and reliability of this prototype exceed what is currently available. The probe offers significant savings because it replaces current tear-down inspections, which are costly and time consuming. In addition, the probe is portable, requires minimal instrumentation and no calibration, and is less expensive to produce than existing devices. This year, the probe technology was licensed to a company for commercialization. Langley is working closely with the company to ensure a smooth transfer to the private sector.

Smart Airplanes Will Fly to Safety

In less than one-sixth of a second, neural net software in a test F-15 jet can restore some control to the pilot after simulated loss of part of a control surface, such as a wing, an elevator, or other damaged-airplane scenarios. In real flight emergencies, grave problems such as partially destroyed wings, fuselage holes, and sensor failures greatly alter how an airplane handles, and the pilot's controls may not work or respond as expected.

The neural net software for airplanes is under joint development by NASA and Boeing. The aircraft's computer compares what is actually happening in flight, using the airplane's sensor data, with how the airplane should fly. If there is a mismatch, because of a failure or accident, the neural net can rapidly learn to trim or adjust the stick, engines, flaps, rudders, and other control surfaces to correct the aircraft's flying pattern for the pilot.

A major technical milestone was reached in February 1998 when the Ames Research Center's NeuroEngineering Group formally delivered the final version of the real-time Dynamic Cell Structure neural network learning software to Boeing. Preliminary F-15 performance evaluations of the software by Boeing were described as excellent, and the incorporation of the software into the newly redesigned F-15 flight processor board has begun. Achieving this software performance represents the culmination of a challenging technical goal and a definite advance in neural flight control technologies.

NASA will complete its portion of the program this year after a number of test flights of a neural adaptive flight controller are performed using NASA's F-15 ACTIVE aircraft at the Dryden Flight Research Center. The F-15's canards, the small wing-like structures forward of the wings, can throw airflow off of the wing to simulate wing damage. Its vectoring jet engine permits pilots to simulate a sudden change in direction that also might occur following damage to the airplane.

After the neural net software is fully developed, tested, and approved, it could be put in commercial jets to help pilots recover control of aircraft during air emergencies. In the future, other systems, such as nuclear power plants, assembly lines, or heating and cooling systems for buildings, could benefit from modified versions of the neural control software.

NASA's F-15 jet aircraft evaluates research on neural network technology to help future airplanes land safely when damaged, such as the F/A-18 (inset) damaged in a mid-air collision.

Goal 2: Emissions Reduction

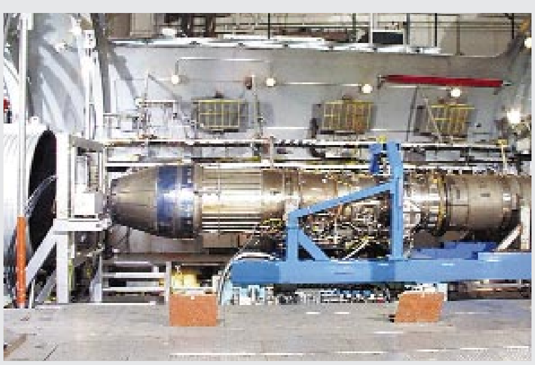
Based on analyses of contributors to worldwide emissions, aviation plays only a small role. To be sure that this does not change, even as air traffic grows, aviation products need to be environmentally friendly. To make sure that the next generation of aircraft are as clean as possible, NASA is working on the necessary technologies. In the global picture, it is in everyone's best interest to ensure a clean environment for future generations.

Currently NASA is focused on research to reduce nitrogen oxides (NO_X), which are emitted from jet engines. The impact of NO_X is that at low altitudes it contributes to smog, and at higher altitudes it can affect the ozone layer.

NASA research is attacking this problem from two sides. First, we want to understand atmospheric chemistry and the impact of emissions. The second approach is to reduce the engine combustion byproducts. The scientific analyses are helping us model the atmosphere to understand and assess its long-term health. Combined with the technology to reduce emissions, these studies will help guide rational decision-making for aviation.

Enabling Technology Goal: Reduce emissions of future aircraft by a factor of three within 10 years, and by a factor of five within 25 years.

Cleaner Engines, Cleaner Skies



The altitude chamber test is characterizing the chemical composition of exhaust from a full-scale turbofan engine.

Developing engines that are low in gaseous pollutants is key to NASA engine research. Engine combustor research at the Lewis Research Center examines such factors as clean and efficient fuel burning and the testing of components developed through design and analysis. These components are then tested in facilities that simulate actual engine operating conditions.

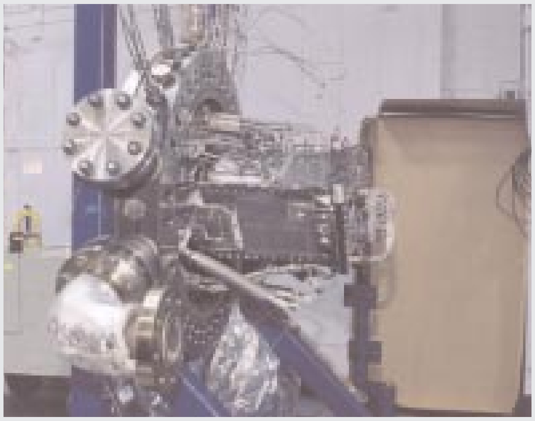
Reducing emissions of NO_X compounds in particular should help in reducing greenhouse gases in the lower atmosphere, which affect the Earth's climate. A goal in this effort is to achieve a 50-percent reduction in NO_X levels from the 1996 international emission standards currently in effect for large turbofan engines. These are engines that power the large commercial aircraft. There is also an equivalent goal to reduce NO_X levels for smaller turbofan engines, which are used in regional aircraft. In addition to reduced emissions, new engine designs must have improved operability and durability, as well as operating costs lower than those of current production engines.

From October 1997 to January 1998, four combustor designs were tested and evaluated: (1) a design with production fuel injectors; (2) one with elliptic-shaped swirlers; (3) one with macrolaminate fuels injectors; and (4) a premix-chamber design. Two important results were obtained. First, the configuration with elliptic-shaped swirlers gives the lowest levels of NO_X at all test conditions. Second, from the test data,researchers were able to derive a relation for NO_X emissions that will help engine manufacturers develop new concepts for combustors with reduced NO_X emissions.

The next step is applying the design to a full-size engine combustor to run a full engine test that provides verifiable emissions levels. Future NASA plans include research to achieve a 70-percent reduction in NO_X levels.

Supersonic Engines Show Superclean Performance

Another aeronautics goal of reduced emissions for future supersonic aircraft has been advanced in the High Speed Research program this year with the



Sector test rig being built at General Electric for testing the lean premixed combustor for a supersonic engine.

completion of a major program milestone. In a cooperative effort involving the Lewis Research Center, GE Aircraft Engines, and Pratt & Whitney, the Lean Premixed Prevaporized (LPP) combustor concept was selected over the Rich-Quench-Lean (RQL) concept for follow-on full-scale technology development.

The LPP concept achieved a dramatic reduction in the production of ozone-depleting NO_X at supersonic cruise speeds without sacrificing combustor efficiency, other emissions, or system safety. In addition, the LPP combustor maintained a combustion efficiency of greater than 99.9 percent with minimal technical or developmental risks. Although emissions and efficiency were major factors in this decision, production and operating costs, weight, system safety, and potential technology development risks were also considered. While not selected, the RQL concept demonstrated exceptionally low emission levels while maintaining high efficiency.

Leading to the combustor downselect decision, subscale combustor tests for the lean and rich burn approaches were conducted. The results of the tests supporting the LPP combustor are very promising, as they continue to demonstrate NO_X levels equal to or better than the program goal of 5 grams of NO_X per kilogram of fuel burned.

By meeting the NO_X program goal with the LPP combustor concept, the future commercial aircraft, the High Speed Civil Transport, is expected to significantly reduce the production of harmful ozone-depleting emissions to better-than-acceptable levels. Results from subcomponent tests in laboratory facilities at the Lewis Research Center have substantially contributed to the attainment of the ultralow NO_X levels.

Spy Plane Sniffs the Stratosphere for Clues

The ER-2 aircraft plays a key role in NASA's study of ozone in the atmosphere at higher altitudes, where supersonic aircraft will operate.

In the early 1970s, the most publicized environmental concern about a future fleet of supersonic transports was the possible destruction of Earth's ozone layer from jet engine exhausts. The ozone layer protects life on Earth by absorbing the Sun's ultraviolet rays.

To address the possibility of ozone destruction, an international team of scientists developed computer models to predict the global impact of various engine exhausts on stratospheric ozone. In addition, a converted military spy plane called the ER-2 and ground-launched balloons were used to make measurements in the stratosphere (the atmospheric region 10 to 30 miles above Earth). The ER-2 was also used to measure engine exhausts from the Concorde supersonic transport.

During the summer of 1997, observations during Northern Hemisphere ER-2 flights completed the data base for assessing the impact of the supersonic jet engines on the atmosphere. Current predictions using these computer models show little impact on stratospheric ozone by a fleet of 500 supersonic transports. In conjunction with this research, laboratory tests of advanced combustion techniques have been successfully performed to reduce ozone-destroying emissions while improving the fuel efficiency of these supersonic engines. This research effort has brought us one step closer to making high-speed travel a reality.

Protecting Our Atmosphere

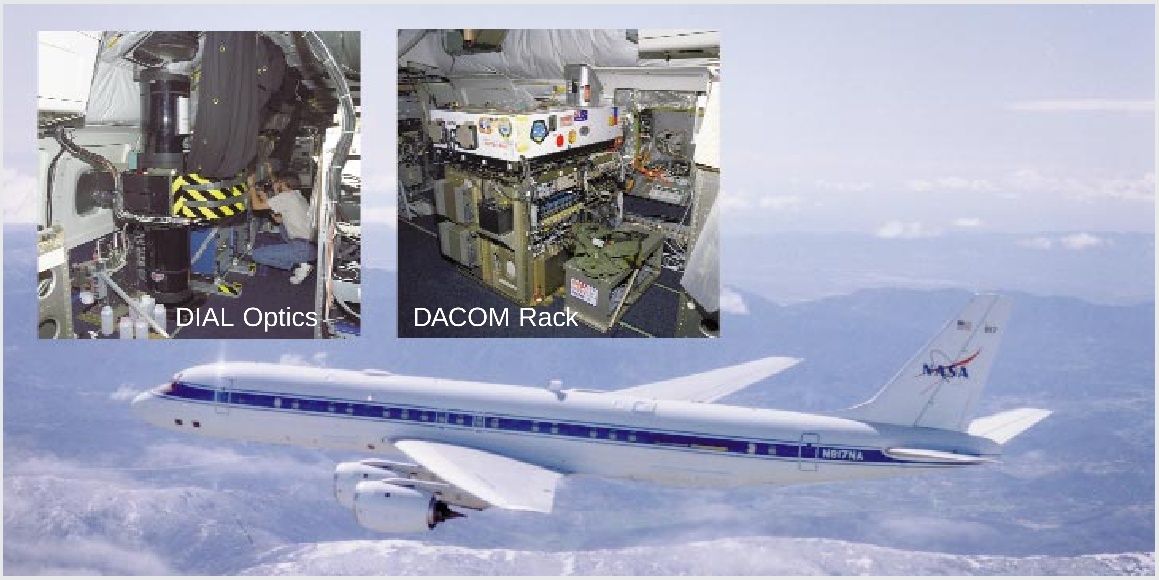
A major milestone this year was the completion of the Subsonic Assessment Ozone and Nitrogen Oxide Experiment (SONEX) mission, which is part of NASA's research focused on understanding the environmental effect of aircraft emissions on the atmosphere. The SONEX mission used direct atmospheric measurements and theoretical models to assess the effect of NO_x emissions from subsonic aircraft (aircraft typical of commercial airliners) on atmospheric ozone.

To predict the impact of the future fleet of subsonic aircraft, researchers must first determine the impact today's aviation is having on the atmosphere. A payload of 16 instruments with principal investigators from NASA, other Federal Government laboratories, and universities flew aboard the NASA DC-8. The mission, led by the Ames Research Center, occurred in the North Atlantic flight corridor, which has several hundred aircraft traveling between Europe and North America daily.

The selection of the instruments was guided by the SONEX science priorities: characterization of air masses, chemical climatology for standard tropospheric constituents, reactive nitrogen source apportionment and photochemistry, and further testing of nitric acid instrumentation. These measurements of carbon monoxide, methane, nitrogen dioxide, carbon dioxide, and water vapor will be used to provide information on the physical and chemical structure of the upper troposphere and lower stratosphere (about 7 miles from Earth's surface) for each set of in situ aircraft measurements.

The summarized data will be available in a report this fall (1998). The SONEX data will be a major contributor to the 1999 Intergovernmental Panel of Climate Change (IPCC) Special Report on Aviation and the Global Atmosphere. Scientists will use the data to improve atmospheric models.

NASA's research data are a valuable contribution to international organizations, such as the United Nations Environment Programme (UNEP), the World Meteorological Organizational (WMO), and the IPCC, for their work on global climate and ozone issues. The NASA assessments will also likely serve as the basis for future emissions standards to be recommended by the International Civil Aviation Organization and assist the Environmental Protection Agency (EPA) in rulemaking and environmental standards.



NASA's DC-8 flying laboratory housed an array of instruments used to study atmospheric chemistry.

Goal 3: Noise Reduction

NASA's 10-year goal is to develop technology to reduce the noise impact from aircraft so that the communities surrounding airports hear one half of the noise that they heard in 1997. In technical terms, this means a 10-decibel (dB) reduction in noise. This amount of noise reduction is similar to the difference in traffic noise from a road with heavy traffic and the same road with light traffic. The source of the noise from today's airplanes is primarily from jet engines, but noise from the airplane itself, particularly during approach, is a strong contributor to the overall noise impact.

The noise impact reduction effort is led by the Langley Research Center and is conducted in close partnership with the Ames and Lewis Research Centers, as well as with industry, academia, and the FAA. This effort began in 1994 and has been very successful in developing analytical computational methods and demonstrating noise reduction concepts that can be used to reduce aircraft noise impact. The dominant sources of noise from the engine are the fan blades and the jet exit, or nozzle. Noise from these sources can be reduced by altering the fan blade and nozzle designs, or by using acoustic liners on the nacelle to absorb the sound. The major contributors to airframe noise are the wing's flaps and slats as well as the landing gear.

Enabling Technology Goal: Reduce the perceived noise levels of future aircraft by a factor of two from today's subsonic aircraft within 10 years, and by a factor of four within 25 years.

Slicing Engine Noise With New Fan Blades

In one project, the Lewis Research Center teamed with the Allison Engine Company to investigate new ways of reducing fan noise from turbofan engines. This work was successful in helping the program meet a major milestone in 1997 with a demonstrated 3 EPNdB (Effective Perceived Noise Level) fan noise reduction. EPNdB is a subjective

A new technology for reducing fan blade noise, designed in partnership with the Allison Engine Company, will benefit both current and future engines.

noise metric used to measure the noise impact during an aircraft flyover.

A 22-inch-scale model was built and tested in the Lewis Research Center's 9x15-Foot Low-Speed Wind Tunnel. The concept tested uses highly swept and leaned stator vane technology. This newly proven technology has been disseminated to industry participants of the NASA program. NASA and industry expect benefits for both current and future turbofan engines.

Stifling Noise Without Choking Performance

The advanced research nozzle, jointly developed by NASA and industry, has been tested in NASA's Aero-Acoustic Propulsion Laboratory.

The research effort to reduce the noise from the exhaust portion of the engine (the nozzle) had a very significant test in 1997, demonstrating a 3-dB jet noise reduction. This joint research and laboratory test project by the Lewis Research Center, GE Aircraft Engines, and Pratt & Whitney has developed separate flow nozzle technology.

Follow-on performance tests for the separate flow nozzle have verified that 3 dB of jet noise suppression was achieved with minimal impact on thrust.

The technology transfer from this test and other jet noise reduction tests, involving AlliedSignal, Allison, and GE, emphasized both noise reduction technology and source diagnostic data to be used in future engine technology development.

Sound Insulation for Engines

Pratt & Whitney's Advanced Ducted Propulsor Model is tested in NASA's 9x15-Foot Low-Speed Wind Tunnel.

Wind tunnel testing of a low-speed fan with advanced acoustic liners successfully demonstrated a major program goal for 1-EPNdB liner noise suppression improvement over current liners. An advanced active noise control concept was also investigated, and this demonstrated that it is technically feasible to reduce fan tones by as much as 10 dB. The elimination of all fan tones in modern turbofan engines can reduce noise by 3 to 4 EPNdB. This joint research effort included NASA and industry partners Pratt & Whitney, Northrop Grumman Corporation, Hersh Acoustical Engineering, Inc., and E. J. Rice Consulting.

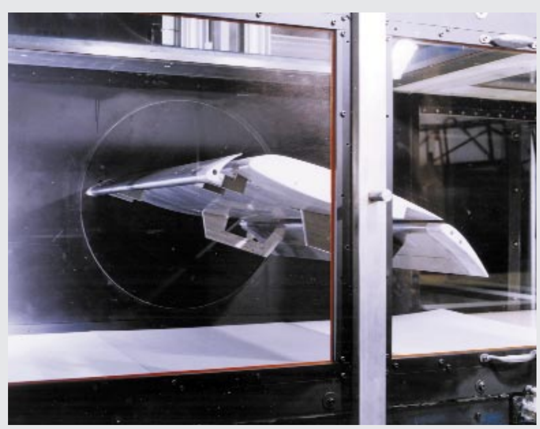
What Is the "Flap" About Noise?

During landing, when airplanes are relatively close to the ground, the airframe noise from the flaps, slats, and landing gear in today's production airplanes almost matches the level of engine noise. If it seems unusual that airframe noise is a strong noise source, think of being in a storm where the wind is howling outside of your home. In future airplanes, airframe noise will be equal to engine noise not only during landing but also during takeoff. The good news is that airframe noise, as with engine noise, can be controlled and reduced with advanced noise reduction technology.

A recent accomplishment within the program is demonstrated technology to reduce flap noise, one of the three main airframe noise sources, by 4 dB. This was accomplished by NASA researchers in partnership with industry, academia, and the FAA. Results of a series of wind tunnel experiments, guided by newly developed noise and flow prediction models, successfully demonstrated significant reductions. Work continues in the program to reduce slat and gear noise, the other main airframe noise sources, so that by the end of the program, total airframe noise will be reduced by 4 dB.

The airframe noise reduction program involved several of NASA's wind tunnels, each one for its unique performance capabilities. The Langley Research Center facilities used included the Quiet Flow Facility, the Basic Aerodynamics Research Tunnel (shown in photo), and the Low Turbulence Pressure Tunnel. Facilities used at the Ames Research Center included the 40x80-foot section of the National Full Scale Aerodynamics Complex, the 7x10-Foot Wind Tunnel, and the 12-Foot Pressure Tunnel.

These accomplishments—the engine, nacelle, and airframe noise reductions—taken together represent a combined aircraft noise impact reduction of 4 dB. A 4-dB aircraft sound level reduction translates into



Redesigned airplane wing flaps and slats incorporating noise reduction technologies are being evaluated in NASA wind tunnels.

a one-third reduction in community noise contour or "footprint" area surrounding an airport. These technologies will enable the U.S. airlines and aircraft manufacturers to meet stringent international and local noise standards. More importantly, these advances, in conjunction with future planned noise impact reduction research, are essential for the general good of the public and for enabling the projected growth of air travel.

Silencing a Wind Tunnel to Measure Noise

NASA has retrofitted the 40-foot by 80-foot test section in the National Full Scale Aerodynamics Complex, the largest wind tunnel in the world, with a new acoustic treatment to make it a premier, world-class anechoic (no echoes) test facility. Background noise and echoes in the wind tunnel's test section cause problems for measuring sound during engine and airframe tests. To reduce noise and echoes in the test section, construction workers have installed a dense acoustic lining in the section's walls, floor, and ceiling. The deeper the acoustic liner, the lower the sound frequency engineers can measure accurately. The insulation material used comes in wedges about 4 feet square and 42 inches deep to cover the entire area, and this is similar to the spun fiberglass commonly used to insulate houses.

Traditionally, wind tunnels are very noisy because of the fans rotating at high speed. However, the 40x80-foot wind tunnel operates at a relatively low fan speed of 180 rpm at its maximum tunnel airspeed of 300 knots. The project's refurbishment and improvement of the wind tunnel's main drive system at lower fan rotation speeds will result in a 20- to 30-percent increase in power to the main fan drive motors while reducing background noise by more than 50 percent. The project also includes the upgrade of antiquated control systems for the model support systems and main fan drive blade pitch control. Programmable logic controllers are replacing the old control systems to provide a more reliable operating system.

The study of noise and how to reduce it is responsible for many of the industry's advancements for existing and new aircraft and rotorcraft. The modification of the 40x80-foot wind tunnel will support the development of the next generation of quieter jet engines and airframes.

The world's largest wind tunnel, located at the Ames Research Center, undergoes sound insulation modifications to improve research for quieter jet engines and airplanes.

Goal 4: Aviation System Capacity

Between 1990 and 1993, each of the 23 major U.S. airports experienced more than 20,000 hours of flight delay. Approximately 64 percent of these delays were attributed to poor weather, and 28 percent were attributed to congestion. These delays cost an estimated $6 billion per year. With the projected growth in air traffic, the number of delays will continue to increase. An additional concern is the rising number of reported surface incidents (287 in the United States in 1996). To address these concerns, the Ames Research Center is leading a program to investigate technologies to increase airport capacity without compromising safety.

Enabling Technology Goal: While maintaining safety, triple the aviation system throughput, in all weather conditions, within 10 years.

Improving Efficiency the "FAST" Way

Air traffic controllers at Dallas/Fort Worth International Airport are evaluating the Final Approach Spacing Tool, which helps manage the airspace more efficiently.

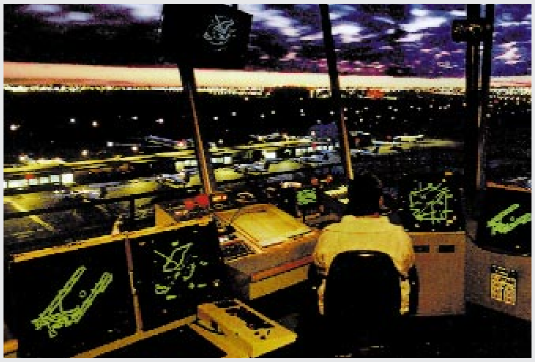
NASA is testing its Final Approach Spacing Tool (FAST) technology at the Dallas/Fort Worth International Airport's Terminal Radar Control Facility. FAST, part of an automated system to manage terminal area traffic, was developed at the Ames Research Center in close conjunction with the FAA. The automated system generates advisories for air traffic controllers to help them manage aircraft arrivals starting at about 200 miles from the airport and continuing to their final approach.

The main function of FAST is to provide advisories to help air traffic controllers manage arriving aircraft and achieve an accurately spaced flow of traffic on final approach. The advisories recommend which runway to land on and the landing sequence for the aircraft. FAST accurately predicts arrival times based on specific knowledge of the type of aircraft, weather conditions, and airport landing procedure. FAST also advises the air traffic controllers how to accurately meet the schedule and assure the required aircraft separations for safety purposes.

Depending on the size of the aircraft, FAA separation criteria for safety require aircraft to stay 3 to 6 miles apart from each other. Air traffic controllers typically add an extra buffer of approximately half a mile between aircraft to guarantee that the spacing requirements will be met. With FAST, controllers can safely reduce that buffer by 0.2 to 0.3 mile. This would substantially increase an airport's capacity to handle arriving aircraft, perhaps by as much as 20 to 30 percent, while reducing arrival delay times by 20 percent. With more than 100 airplanes arriving each hour at a major airport such as Dallas/Fort Worth, this should result in significant savings to the airlines and potentially lower ticket prices for passengers.

Every Minute Counts

The Surface Movement Advisor system is primarily a set of computers and software that electronically connects information gathered by the three principal entities that make an airport run—the local airport authority managing the airport's ramp areas, the airlines managing the gates, and the FAA's air traffic controllers. Until now, the continuously gathered information was kept separate, and these groups had only occasional access to each other's information. This is the first automated system that provides all of the gathered information to each group, helping them make better collaborative operational decisions.



The Surface Movement Advisor, jointly designed by engineers, air traffic controllers, and airline and airport management staffs, was evaluated at Atlanta Hartsfield International Airport.

This system, developed at the Ames Research Center, can make an airport run more efficiently by reducing ground operations bottlenecks, thus allowing planes to be serviced and dispatched more quickly. The FAA selected Atlanta Hartsfield International Airport in 1995 as the field test site for the system. In June 1996, Delta Air Lines, which has nearly 700 flights per day from Atlanta Hartsfield, and several other airlines began daily use of the system.

Since the system has been in use, it has reduced airline taxi departure times by more than 1 minute per flight. With well over 1,000 daily departures from the airport, the time savings means passengers will less likely miss their flights and will spend less time waiting. A savings of 1,000 minutes or more also means a daily savings to the airlines of at least $40,000 to $50,000 in direct operating costs, or $16 to $20 million saved annually, just at Atlanta Hartsfield. Both the savings in time and costs will benefit air travelers.

Helping Pilots See the Way

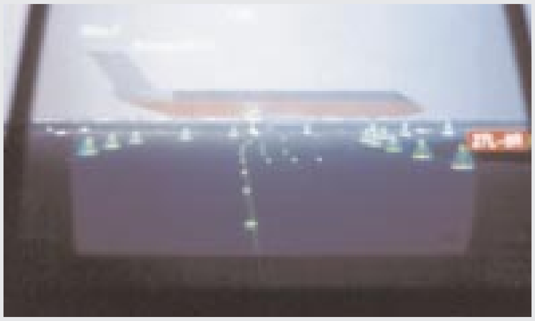
Over the next decade, commercial airline traffic is expected to increase by 30 percent. As the traffic increases, airline schedules become tighter and more intertwined, increasing the opportunity for weather-related delays at major airports to propagate and disrupt schedules nationwide. Technologies such as the Taxiway Navigation And Situation Awareness (T-NASA) system, developed by human factors psychologists at Ames, will minimize weather-related disruptions to airport surface operations, particularly at large, complex airports such as Chicago's O'Hare.

T-NASA is a combination of software and navigational displays incorporated into the cockpit. T-NASA is not automated, so pilots will continue to manually control taxi maneuvers. The goal is to safely get the aircraft from the gate to the runway and from the runway to the gate as efficiently as possible, even when visibility is poor.

T-NASA has three components. The Head-Up Display (HUD), a glass visor in front of the cockpit windshield, shows the cleared taxi route in a "virtual reality" format. The HUD depicts the edges of the taxiway with a series of virtual "cones" and the centerline with virtual centerline markers. As the plane moves, the cones and markers move and change as if they were actual objects on the airport surface, so the pilot's cleared route looks like a virtual highway on the ground.

On the instrument panel, an electronic moving map of the airport shows the current ground position of the pilot's aircraft and all other aircraft present. The moving map depicts the pilot's cleared route with a magenta ribbon. With just a glance at the moving map, both the pilot and copilot can determine where their aircraft is with respect to the cleared route.

The third component is a traffic warning. Produced via virtual three-dimensional audio techniques, the warning sounds as if it emanates from the direction of the hazard. This feature, along with the moving map, is designed to greatly enhance a pilot's awareness of potential traffic hazards. One of the most potentially serious

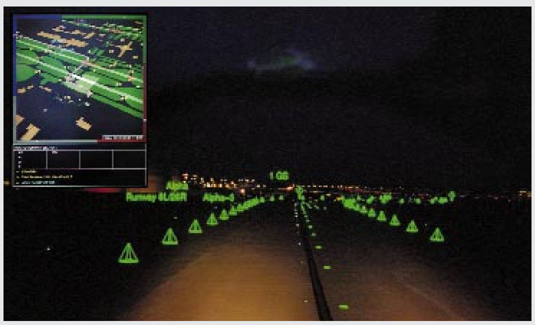


The NASA-developed cockpit display system shows the cleared taxi route on a glass visor in front of the cockpit window.

situations occurs when crews fail to obey a "hold short" command and stray onto an active runway. T-NASA improves compliance by flashing a bar at the hold short position on the moving map and putting up a virtual stop sign on the HUD.

T-NASA, in combination with other technologies to improve air systems operations, will help increase the safety, efficiency, affordability, and reliability of air travel.

The Real Deal—Flight Testing at Atlanta Airport



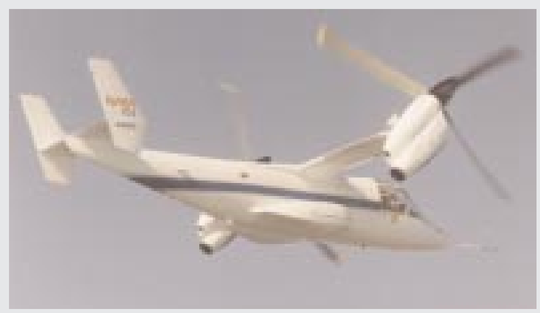
Successful integration and demonstration of tools designed to safely increase airport operations in all weather conditions.

In August 1997, the joint NASA-FAA Low Visibility Landing and Surface Operations (LVLASO) program brought together and flight-demonstrated several technologies aimed at reducing the growing number of ground accidents and close calls. LVLASO integrates ground and airborne system technologies into one super system to increase the situational awareness of both pilots and controllers, allowing pilots to safely approach a runway for landing, rolloff, and taxi in any visibility.

On the ground was an FAA-developed system of ground surveillance sensors and other equipment. Aboard NASA's Boeing 757 research aircraft were the airborne systems and displays. The cockpit display system included the Roll-Out Turn-Off (ROTO) guidance subsystem developed at the Langley Research Center. This system aids the pilot during the rollout and turnoff portion of the landing (after touchdown, rolling down the runway and exiting the runway onto the taxiway). The second system used as a pilot aid during taxi was the T-NASA display subsystem described above.

As the NASA 757 approaches the runway, computer-generated graphics outline the correct runway and its precise location on a head-up display mounted between the pilot and the windscreen. Upon contact with the ground, a "head-down" moving map display shows the pilot his or her location on the runway and taxiway system, as well as the location of all other active aircraft. Aircraft location is provided by the GPS satellite system. Digital datalink communications were used to supplement voice communications between the pilot and air traffic controller, greatly eliminating the possibility of miscommunication. Using this system, taxi speeds can be safely increased by as much as 25 percent. Production versions of this system will play a critical role in helping reach the goal of tripling our Nation's aviation system capacity while maintaining safety in all weather conditions.

Land-Anywhere Airplane a Solution for Airport Congestion



The XV-15 Tiltrotor can take off vertically and hover like conventional helicopters, as well as fly at a top speed of 345 miles per hour when its propellers are rotated forward for flight.

The XV-15 Tiltrotor Research Aircraft was developed 20 years ago under a joint NASA-Army-Bell program at the Ames Research Center. "X" is the designation for experimental aircraft, and "V" stands for vertical. Today, the XV-15 is the primary testbed for evaluating new tiltrotor technology concepts, such as a variable-diameter tiltrotor, that could further develop the aircraft's capability as both a helicopter and a turboprop airplane. Flight research demonstrated that its noise "footprint" is 30 percent lower than conventional helicopters—a very significant accomplishment that is important for community acceptance.

In July 1999, Bell Helicopter Textron Inc. of Forth Worth, Texas, and Boeing Defense and Space Group's Helicopters Division in Philadelphia plan to conduct the first flight of the Nation's first civilian tiltrotor, the Bell-Boeing 609. The company is also building the world's first production tiltrotor for military use, the V-22 Osprey, which can carry 24 combat-ready troops if needed. Both the 609 and V-22 are direct descendants of the XV-15.

Ames scientists, engineers, and technical staff are currently working on a tiltrotor concept for a 40-passenger civil tiltrotor, which will push the technologies to a new level. The potential for dramatically alleviating airport congestion from both aircraft as well as ground vehicles is offered by the tiltrotor. The Department of Transportation concluded in 1995 that a new air transportation system based on civil tiltrotor technology could be created and that a 40-passenger civil tiltrotor is feasible technically and economically, as well as being environmentally sound.

Control Tower Simulator Combats Congestion

NASA has begun construction of a full-scale air traffic control tower simulator that will provide—under realistic airport conditions and configurations—a facility that will test ways to combat potential air and runway traffic problems at commercial airports. Jointly funded by NASA and the FAA, the $9.3 million, two-story building called the Surface Development and Test Facility (SDTF) is located at the Ames Research Center.

The SDTF will be able to simulate any airport in the world. The tower cab, located on the facility's second floor, will have reconfigurable site-specific displays, such as terminal area radar, surface radar, and weather, installed based on FAA specifications. The three-dimensional visual data base of the airport will be viewed through the 360-degree window of the simulator. The visual scene, along with specific airport traffic patterns and operating procedures, will provide a very credible simulation capability. Twelve rear-projection video screens will provide a seamless 360-degree high-resolution view of the airport or other scenes being depicted. These image generators will provide a realistic view of weather conditions, environmental and seasonal effects, and the movement of 200 or more active aircraft in the air or on the ground. Computer software, provided by Raytheon Systems Company of Arlington, Texas, will be integrated with the tower simulation hardware technologies to support both radar and out-the-window visual simulation.

The imaging system will be powered by supercomputers and the remainder of the simulation by approximately 100 Pentium processors. Video cameras will record air traffic controllers' activities for human factors research and also provide visitors and researchers unobtrusive remote viewing of simulations in progress. Ramp controllers, airport operators, simulation engineers, software developers, and researchers will be located in separate work areas on the facility's first floor. Also located on the first floor will be a briefing room for simulation participants and visitors, as well as all the computers, displays, and communications links necessary for a fully operational airport.

The SDTF will be the only facility of its kind in the world. It will allow the commercial aviation industry to study and correct potential problems in a safe setting before they become actual problems. Researchers will look primarily at the feasibility, safety, reliability, and cost benefits of technologies prior to incorporating them into airports. In addition, testing will provide information that may assist in developing proposed changes to airport ground procedures and to the construction of new airport facilities.

The 360-degree Tower Cab replicates Level 5 control towers with a modular design that allows its layout to match towers of major airports.

Goal 5: Affordable Air Travel

For the aircraft manufacturers, a major challenge is to reverse the trend of increasing aircraft ownership and operating costs. Dramatic savings in design time, manufacturing, and the cost of certification are needed.

NASA's research efforts will focus on innovative design techniques and structural concepts to enable the U.S. aviation industry to significantly advance today's state of the art for aircraft and engines. Only by increasing air system efficiency to reduce delays and reducing aircraft development costs will air travel become more affordable.

Enabling Technology Goal: Reduce the cost of air travel by 25 percent within 10 years, and by 50 percent within 25 years.

Stitching Together Composite Wings

The Advanced Stitching Machine prototype is a technological paradigm shift featuring revolutionary processing combined with high-speed stitching capability for composite wings.

In 1997, the Advanced Stitching Machine (ASM), located at Boeing's Stitched Composite Development Center, became operational. The facility is named after Langley researcher Marvin B. Dow in honor of his contributions to stitched composites technology. This technology, developed by NASA and industry, is a critical milestone on the way to realizing the full potential of composite airframe structures. Composites offer the potential to reduce airframe production and operating costs by reducing weight, increasing efficiency, and decreasing the cost of airframe structures. However, a cost-effective means for manufacturing large composite structures is required before composite wings can be used on commercial transports. The ASM provides this technology.

The joint NASA-industry development of textile composite technology has been the breakthrough that has overcome the historical barrier issues of high cost and low damage tolerance associated with composite primary airframe structures. The Langley Research Center played a leading role in developing and evaluating several early textile concepts. This led to the conclusion that the combination of large textile preforms, stitched together to form large integral components and then fabricated with a resin film infusion process, was the most effective concept for a wing structure.

Equipped with four stitching heads, this massive machine is able to stitch one-piece aircraft wing cover panels 40 feet long, 8 feet wide, and 1.5 inches thick at rates of up to 3,200 stitches per minute. The process also eliminates the need for thousands of metal fasteners because the skin, stiffeners, intercostals, and spar caps can be stitched into one piece. The estimated cost savings from this technology over conventional aluminum wing structures is 20 percent.

The panels currently being stitched on the ASM will eventually be used in full-scale ground tests of a semi-span composite wing representative of a commercial jet transport wing. The testing of a 40-foot semi-span wing will take place at Langley's Structures and Materials Laboratory in 1999. The tests will simulate various levels of damage to ensure that the composite wing meets FAA standards. The development of this technology, which provides a cost-effective manufacturing process, is a significant step toward the application of composite wings to commercial aircraft and achieving the goal for affordable air travel. Continued testing to further verify the performance and increase the maturity and confidence level of this technology is in progress.

Far-Out Look Not So Far Away

Analysis and testing of futuristic concepts and technologies will greatly expand design options for future aircraft.

In 1997, Langley researchers conducted the first of a series of wind tunnel tests on an unconventional configuration, called a blended wing body. These tests showed that controlling that design is possible but will require advanced flight control systems. Ride and handling qualities are important critical issues for these types of configurations.

Preliminary analyses indicate that the configuration has the potential to outperform all conventional aircraft of a similar size, range, and level of technology. A configuration that could carry 800 passengers over 7,000 miles at a cruise speed of approximately 560 mph would have potential benefits of reducing fuel burn and harmful emissions per passenger mile by almost a third in comparison to a notional conventional aircraft of the same size and range.

The idea for "flying wing" airplanes is not new. However, to be commercially viable, many challenges, such as noncircular pressurized fuselage structures and stability and controls, must first be addressed. In a conventional circular fuselage section, internal pressure is carried efficiently by a thin skin via hoop tension. If the section is noncircular, internal pressure loads induce large bending stresses.

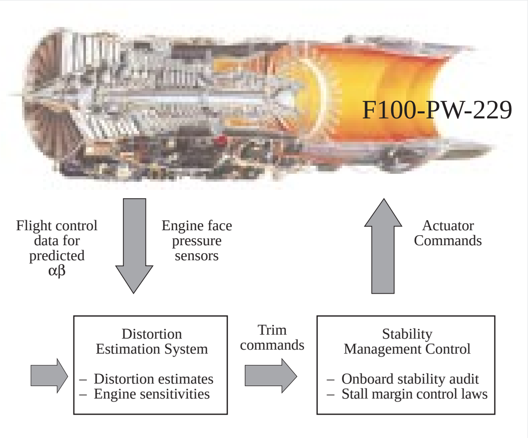
The pursuit of the blended wing body and other revolutionary configurations plays a significant role in pushing the advancement of technology. The benefits of these technologies for future aircraft performance, cost, and environmental compatibility will help U.S. industry successfully compete in the 21st century.

Smarter Engine Passes Tests With Flying Colors

NASA recently concluded flight demonstrations of an advanced high-stability engine-control (HISTEC) system that is expected to significantly increase future propulsion system performance in both military and commercial aircraft turbine engines. The system, called Distortion Tolerant Control, incorporates an aircraft-mounted, high-speed processor that senses changes in airflow at the front of the engine and allows the system to automatically command trim changes to the engine to accommodate changing distortion conditions. This allows the engines to operate with more stability under adverse or turbulent airflow conditions.

The primary benefit of Distortion Tolerant Control is its ability to set the margin of stability, online and in real time. This can allow the built-in stall margin to be reduced, which can then be "traded" for increased performance, decreased weight, or both. The result will be higher performance military aircraft and more fuel-efficient commercial airliners.

The HISTEC system was successfully flight tested at the Dryden Flight Research Center on a highly



Advanced control system technologies to significantly increase both civil and military aircraft engine performance are being tested on the Pratt & Whitney F100-PW-229 engine.

modified F-15 jet, which is exploring a variety of advanced control system technologies. The F-15's right engine was heavily instrumented for the HISTEC experiment, while its left engine remained in the standard configuration. Propulsion testing on only one of the two engines reduces the flight-safety risk inherent with most new technologies.

Project pilots flew the modified F-15 through a variety of maneuvers designed to create unstable or distorted airflow conditions in the engine air inlets, including flight angles (angle of attack) up to 25 degrees, full-rudder sideslips, wind-up turns, split-S descents, and simulated fighter maneuvering. Test-point speeds ranged from Mach 0.3 to Mach 1.6, at altitudes from 5,000 to 45,000 feet. The flight data was fed into a stability management control in the aircraft's electronic engine control computer, which then gave trim commands to the right engine to accommodate the distorted airflow.

The HISTEC research is sponsored and managed by the Lewis Research Center, while Dryden managed the flight test phase. Partners include engine manufacturer Pratt & Whitney of West Palm Beach, Florida, which developed the distortion estimation and stability management systems; Boeing Phantom Works (formerly McDonnell Douglas) of St. Louis, Missouri; and the U.S. Air Force's Wright Laboratories, Wright-Patterson Air Force Base, Ohio, which owns the aircraft and provided one of the five pilots who flew the missions.

Testing, Testing . . .

The Systems Research Aircraft helps accelerate the development of innovative high-risk concepts into flight-proven designs.

During the past year, the F-18 Systems Research Aircraft has flight tested several technologies that could help reduce the cost of air travel. These technologies include a smart skin antenna (which uses the aircraft skin for a UHF-FM antenna), a cost-saving avionics design approach, and 10 distinct hardware experiments comprising 34 flight tests. The Systems Research Aircraft also helps decrease development time for new aircraft, accelerating development of innovative high-risk concepts into flight-proven designs. Revolutionary concepts tested this year include an air data probe with neural network air data computations, new flight control computer systems, new methods of flutter certification using a "flutterometer" concept, and air-to-air GPS concepts.

A Little Air Rubs Friction the Right Way

Engine nacelle with Micro-Blowing Technique skin is prepared for testing in United Technologies' wind tunnel.

One of the most challenging areas of research in aerodynamics is the reduction of skin friction, especially for turbulent flow. Reduced skin friction means less drag. For aircraft, this can lead to less fuel burned or to a greater flight range for a fixed amount of fuel.

An innovative skin-friction reduction technique, the Micro-Blowing Technique (MBT), was invented in 1993 by Dr. Danny Hwang of the Lewis Research Center. Hwang has received a Superior Accomplishment Award, a Space Act Award, and a Space Act Board Award (NASA Inventions and Contributions Board) for the invention of the

MBT. The technique is a unique concept in which an extremely small amount of air is blown vertically through a specially designed porous plate with microholes. This reduces the surface roughness and viscous shear drag, thereby reducing skin friction. It can be used for aircraft or marine vehicles, such as submarines (where water is blown through the holes instead of air).

In September 1997, a joint program of Lewis, United Technologies Research Center, Northrop Grumman Corporation, and Pratt & Whitney was completed. A 30-inch engine nacelle with an MBT skin was tested in United Technologies' wind tunnel. The results of the experiment indicated that skin-friction reductions of 50 to 70 percent are possible over portions of the nacelle, with the addition of only small amounts of blowing air. Tests applying MBT to supersonic flow (that is, flow conditions greater than the speed of sound) and the search for an optimal MBT skin are continuing.

Reducing Parts to Reduce Costs

Advanced technologies, such as integrally stiffened panels, will enable a significant reduction in the number of parts required to manufacture an aircraft fuselage.

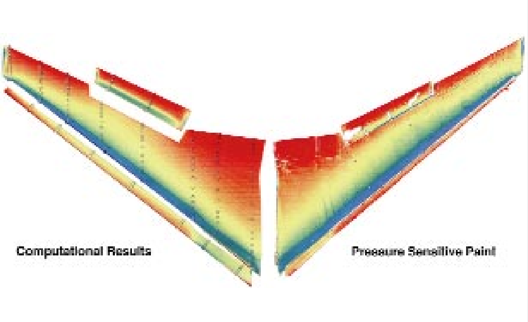
The airframe industry has identified reductions in the production and ownership cost of airplanes to be critical factors in reducing the cost of air travel. Reducing the number of parts and the number of assembly steps required in the manufacturing process is one means of reducing cost. Researchers at the Langley Research Center, in conjunction with industry personnel, have been studying the feasibility of manufacturing parts of the fuselage structure with the stiffeners as a single piece, called integrally stiffened structures.

In 1997, researchers built and tested two metal panels to demonstrate the damage tolerance of an integrally stiffened fuselage structure. The panels were fabricated with curvature and stiffener spacing that represented a typical fuselage structure. The process provided a substantial reduction in the number of parts over conventional construction. It also has the potential to reduce the overall weight and fuel requirements of the aircraft, as well as decrease the manufacturing cost.

The tests demonstrated the tendency of a crack to turn at the stiffeners—an indication of the damage tolerance of the structure—and the ability of the panels to support the required load after the crack grew. During the next year, cost modeling and performance predictions will be completed, along with additional testing to verify the performance predictions.

The goal of the Integral Airframe Structures program is to demonstrate that integrally stiffened airframe fuselage structures designed for typical airframe loads offer significant part count reduction. When compared with conventional riveted aircraft structures, the integral airframe structures should also be at least 20 percent lower in cost, with no additional gain in weight.

Design Tools Can Include Painting



Real-time acquisition of complete surface pressure maps using pressure-sensitive paint reduces data collection and analysis time by weeks.

Current aircraft design and development processes involve a series of independent, time-consuming steps. The wing of an aircraft is designed and optimized for the cruise point, and then components such as the propulsion system are integrated into the design.

Researchers in NASA's Advanced Subsonics Technology program are working to reduce the design cycle time by delivering integrated design methodologies and new aerodynamic concepts. These concepts and tools will enable revolutionary aircraft designs and faster design cycles while reducing aircraft operating costs, environmental impacts, and aircraft development risks.

With the completion of a midterm assessment of the integrated wing design technologies, the Langley and Ames Research Centers reached a critical milestone toward the goal of reducing the direct operating cost and development time of aircraft. The assessment focused on the benefits resulting from technologies developed in this area. Of particular significance are the benefits from a pressure-sensitive paint system developed at Ames for use in wind tunnel research and improved methods for designing a cruise wing configuration. The pressure data compared very well to data obtained from a solution using computational fluid dynamics software codes. The improved technologies in these two areas contribute to reducing the time to design an aircraft by 3.5 months and reducing the cost of developing an aircraft by 1 percent.

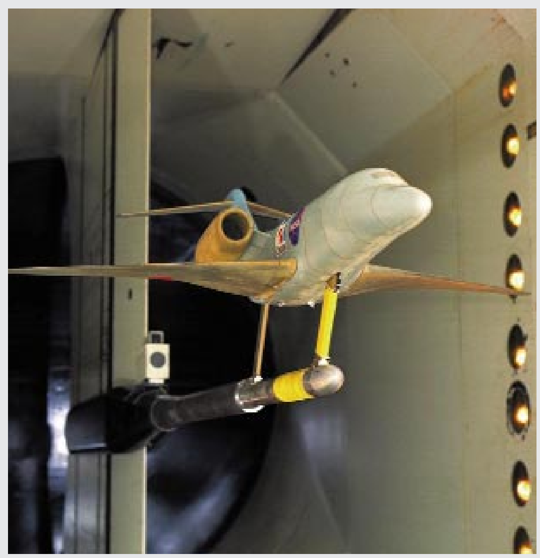
Cryogenics Makes Conditions Real

NASA's cryogenic wind tunnel simulates flight conditions for scale models—a critical tool in designing airplanes.

The National Transonic Facility (NTF) at the Langley Research Center is a unique facility that provides testing capability at very high Reynolds numbers, allowing accurate simulation of the flight conditions for large aircraft. This accuracy provides the capability to develop aircraft with improved efficiency—leading to reductions in fuel usage and operating cost. The key factor of this facility is spraying the air with cryogenic liquid nitrogen, producing very cold conditions.

In December 1997, the world's largest wind tunnel motor was installed in the NTF. The new motor and fan drive system replaces an aging system and will improve productivity by increasing the wind tunnel's operating envelope, reducing the time to reach a test point, and simplifying the drive system.

Controlling Wing Flutter



Critical flight conditions, such as wing flutter, can now be studied in an environmentally friendly wind tunnel.

Representing the Nation's only capability for performing flutter wind tunnel tests, the Transonic Dynamics Tunnel (TDT) is one of Langley's most productive tunnels. The wind tunnel recently completed the transition from using a greenhouse gas (R-12 Freon) to a more environmentally friendly gas (R-134A Freon).

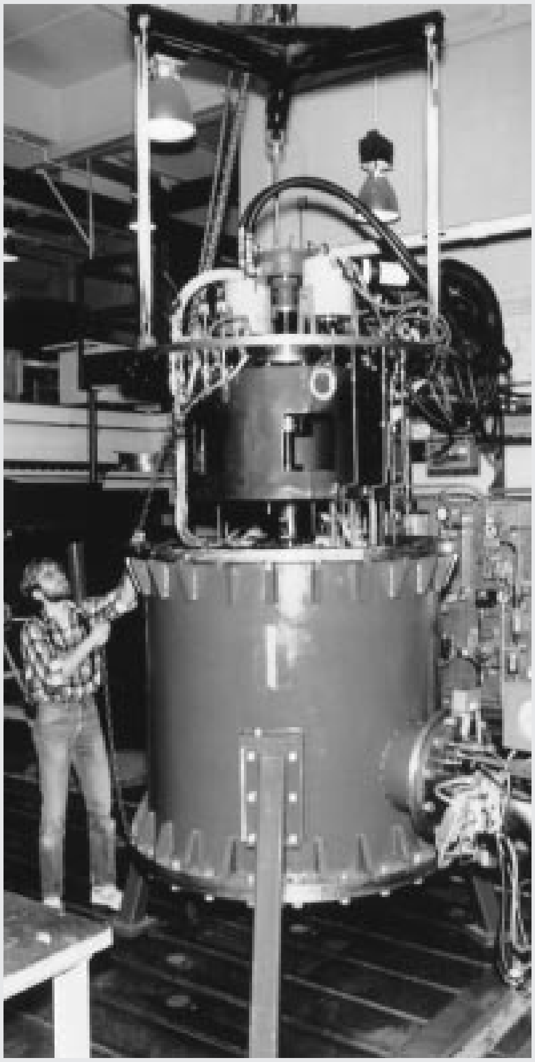
Flutter is the small amount of movement airplane wings experience from the aerodynamic forces of flight. This unique facility is used to validate aircraft designs with respect to the limits of allowable flutter motion. The study of flutter examines how an aircraft wing and the mechanical elements of the wing, such as ailerons and flaps, will move in response to the air flowing around it during flight. Wings are not completely rigid elements, and are designed with some flexibility to bend and twist. However, this small movement must be controlled through the structural design, ensuring that it does not weaken the wings or degrade aircraft flight performance. The flutter test results provide valuable information to designers, allowing the development of structurally sound, lighter weight, more efficient, and safer aircraft.

New Magnetic Bearings Being Taken for a Spin

The Dynamic Spin Rig (DSR) at the Lewis Research Center is used to perform experiments on various rotating engine components (fan and compressor blades). After rotating and vibrating components in a vacuum chamber to characterize and verify their structural dynamic behavior, an analysis of the behavior can then be transferred into new engine designs. Reducing vibration can decrease the amount of high-cycle fatigue failures, improving engine reliability and reducing maintenance costs.

Recently, a magnetic bearing was integrated into the DSR to provide magnetic suspension and mechanical excitation of the rotor to induce turbomachinery blade vibrations. The new magnetic suspension and excitation system has provided enhanced testing capabilities by allowing high rotational speeds for a longer duration and producing higher blade vibration amplitudes than the existing electromagnetic shakers.

Experiments were successfully conducted with the University of California at San Diego on the damping of composite plates. These experiments demonstrated the system's robustness for long-term testing. Also, the team discovered that the bearing could use feedback from the blade's strain gauges to provide blade damping. This is an additional benefit because insufficient blade damping is a critical problem in advanced turbomachinery blades.



New magnetic suspension provides enhanced testing capabilities for rotating engine components, contributing toward improving engine designs.

The success of the initial work led to the development and design of a full magnetic suspension system (using three magnetic bearings) for the DSR. While the new magnetic suspension has provided enhanced testing capabilities (which is vital in testing new designs with higher performance requirements—for example, higher speeds), it is also enabling the further development of magnetic suspension systems that could replace conventional roller bearings in future turbine engines. By replacing conventional roller bearings, aircraft engines would no longer require the costly oil lubrication systems that are in today's engines.

Dedication of High-Tech Engine Materials Lab

In the largest Construction of Facilities project undertaken at the Lewis Research Center in 20 years, Lewis and a team of contractors recently completed a $19 million renovation of Building 49. The 50-year-old structure now features 60,000 square feet of state-of-the-art laboratory space that will enhance the ability of Lewis to develop improved metal and polymer materials for aircraft engine components.

"I'm so proud to be here on this happy occasion that underscores how Lewis is helping the Nation to lead in materials and structures through advanced research," U.S. Representative Dennis J. Kucinich said during the ribbon-cutting ceremony on December 1, 1997. "Thanks to all of you for the work that you do."

Center Director Donald J. Campbell applauded the project team, which in spite of numerous challenges accomplished the 18-month renovation on time and within budget guidelines. "This project was made possible through a diverse, dedicated, and highly skilled team made up of civil servants and contractors," he said. "Using all of our resources fully is what has made Lewis successful."

Lewis employees join Ohio Congressman Dennis Kucinich (second from right) and Center Director Donald Campbell (far right) to rededicate the Composite Technology Center.

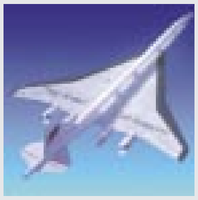
Pillar Two: Revolutionary Technology Leaps

Aviation has always been an exciting and risk-taking endeavor. With a strong partnership among industry, Government, and academia, there has been an incredible history of innovation and technological breakthroughs.

The pioneering spirit at work in the X-1 and X-15 projects is being recaptured through the renewed emphasis of X-planes. The breakthrough work accomplished by these projects will move our country forward with an improved base of technical knowledge.

In addition to the tools of flight, next-generation design tools will revolutionize the aviation industry. Design was once simply applying lead to paper. Research in information technology will elevate the power of computing tools through fuzzy logic and artificial intelligence. These tools will integrate multidisciplinary product teams, linking design, operations, and training data bases to dramatically cut design-cycle times.

Goal 6: High-Speed Travel



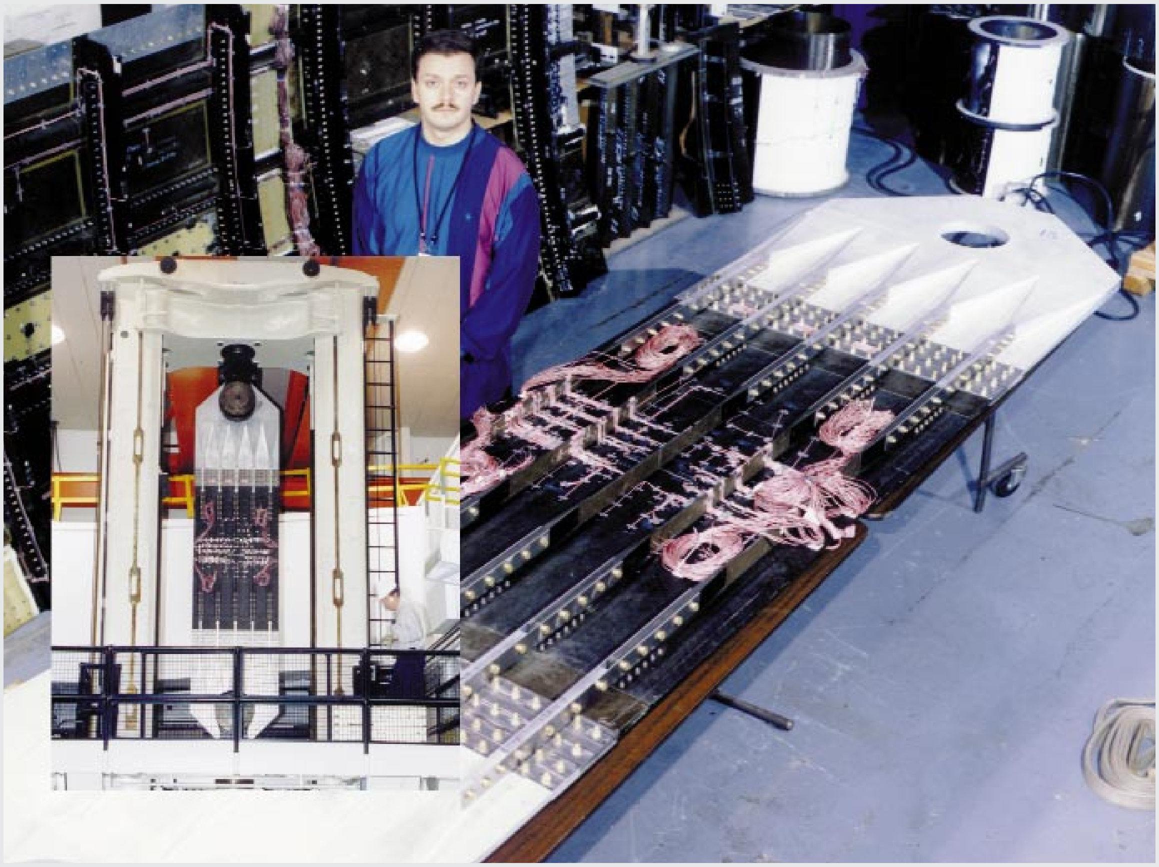
To ensure our Nation's long-term aeronautical leadership, we must look to a future of value-based competition. Simply put, the United States must bring to market products that dramatically benefit the traveling public and do so without harming our environment.

Since the sound barrier was broken 50 years ago, most modern fighter aircraft have the capability to fly faster than the speed of sound. However, today's supersonic engines cannot meet the public's standards for a clean and quiet community. To bring this capability to commercial air travel, a number of technical barriers must be overcome. Among NASA's technology goals for removing the environmental and economic barriers are: (1) quiet supersonic engines able to meet subsonic aircraft noise standards; (2) clean supersonic engines with emissions 75 percent lower than today's aircraft; and (3) low-cost materials and structural concepts for affordability. The result will revolutionize overseas air travel.

Enabling Technology Goal: Reduce the travel time to the Far East and Europe by 50 percent within 25 years, and do so at today's subsonic ticket prices.

Materials to Withstand a Supersonic Challenge

Future supersonic transports will fly at speeds greater than 1,500 miles per hour, at altitudes of 65,000 feet, and with surface temperatures of more than 300 degrees Fahrenheit. Currently available metals are either too heavy or cannot withstand the temperatures. Researchers at the Langley Research Center have developed a special new composite material to meet the temperature and durability



In recent testing, panels of a special composite material were subjected to more than 400,000 pounds of force before they cracked.

requirements of this aircraft. The composite, PETI-5 (Phenyl Ethynyl Terminated Imide) is the fifth formulation developed. Composite materials made from graphite fibers and PETI-5 are necessary to both withstand the high temperatures and to make the plane strong enough and light enough to be economically viable.

In a recent test, two 40-inch-by-80-inch PETI-5 panels were subjected to more than 400,000 pounds of force before they cracked. Structural tests similar to these are necessary for FAA certification of airplane structures. The PETI-5 structure tested has promise as the primary wing and fuselage material for a supersonic transport. In future tests, researchers will evaluate skin panels with foreign object damage, repeat the first two tension tests on other panels, and perform compression tests on a series of flat and curved panels. Eventually, a large section of a fuselage will be tested.

A 75-member committee that studied new technologies on behalf of *Research and Development Magazine* honored the PETI-5's development as part of the magazine's annual "R&D 100 Awards," a worldwide competition for the 100 most technologically significant new products and processes of 1997. PETI technology has already been transferred to industry, with licensing agreements to four different companies: Culver City Composites, Culver City, California; Cytec Engineered Materials, Havre de Grace, Maryland; Fiberite, Greenville, Texas; and Imitec, Schenectady, New York.

The agreements position each of the companies to support advanced composites for a future supersonic civil airliner. Because of the material characteristics of PETI-5, it is the only material that meets the needs for future high-speed civil transports. This is the only market that licensees are presently pursuing. Other markets may become viable as the quantity of material produced increases and the cost of the material decreases.

"Flight" Testing for a Lifetime of Performance

In early 1998, researchers at the Langley Research Center completed more than 15,000 hours of

Numerous material samples are used for long-duration testing under realistic conditions—a critical step in the process of building confidence in the long-term performance of new materials.

flight profile testing on structural samples of new high-temperature materials. Flight profile tests are designed to simulate the forces and temperatures that an aircraft would experience during the entire flight, including the taxi, climb, cruise, descent, and landing stages. The test materials (called IM7/5260 and IM7/K3B) are polymeric matrix composites that resemble PETI-5. The test results showed that the materials performed as expected without experiencing any degradation. Researchers will continue testing these samples until more than 60,000 flight profile hours have been achieved. These numbers are derived from the expected 20-year life expectancy of an airplane for which an average of 4,000 hours per year is accumulated in flight and 3,000 hours per year is spent at cruise conditions of 350 degrees Fahrenheit.

The results of these tests will help us understand and predict the long-term behavior of the materials. This information is critical in determining whether these new composite materials will perform as expected throughout the service life of the aircraft. The results will also be used to validate the accuracy of short-term accelerated tests in predicting long-term degradation. Before a future commercial supersonic transport can be built, industry and the FAA must have confidence in the long-term performance of the materials.

Vision for a New Nose

Pilot evaluates video and high-resolution sensor displays that may someday replace front cockpit windows in supersonic transports.

Current supersonic transports such as the Concorde mechanically "droop" the aircraft nose downward during takeoffs and landings to allow the pilots to see. NASA researchers are working to develop the technology that would replace the forward cockpit windows in future supersonic passenger jets with high-resolution sensor displays. These displays would use computer-enhanced video images to replace the view out of the front windows. The system would guide pilots to an airport, warn them of other aircraft near their flight path, and provide additional visual aids for airport approaches, landings, and takeoffs.

In June 1997, a series of flight tests were performed with the NASA 737 research aircraft to determine how well pilots adjusted to an external vision system that is accompanied by side windows. The pilots experienced no significant difficulties. Researchers are continuing studies on external vision display technologies, conducting tests in various flight simulators at the Langley Research Center.

These tests are necessary steps toward developing an aircraft without the heavy and expensive "nose-droop" design, saving an estimated 20,000 pounds (about 2.5 percent) in gross weight. A longer fixed nose design could then be used to reduce drag, which would in turn result in additional fuel and weight savings. An external vision system could also provide safety and performance capabilities that exceed those of unaided human vision.

Russian Supersonic Airplane Is a U.S. Testbed

The Tu-144LL flying laboratory lands at Zhukovsky Air Development Center near Moscow, Russia.

NASA, a team of U.S. aircraft and engine manufacturers, and Russia's design laboratory, Tupolev, have used a Russian Tu-144 supersonic jet as a flying laboratory. Data collected on the six experiments aboard the Tu-144LL, and from two ground experiments, will be used to develop technologies for a future supersonic passenger jet that is economically viable and enivronmentally compatible. The U.S. industry team for the Tu-144LL project was led by Boeing, with help from McDonnell Douglas, Rockwell, Pratt & Whitney, and General Electric.

During a 15-month period (January 1997 through March 1998), the Tu-144LL High-Speed Flight Experiments program accomplished several objectives. Eighteen research flights were completed involving six flight experiments that studied aerodynamics, thermodynamics, structural and cabin noise, propulsion systems environment, aircraft handling qualities, and landing characteristics. Using the Tu-144LL to conduct flight experiments will allow researchers to compare full-scale supersonic aircraft flight data with results from models in wind tunnels, computer-aided techniques, and other flight tests. After a review of the program results, NASA, Boeing, and Tupolev are planning further flight research activities using the Tu-144LL flying laboratory.

The Art and Science of Landing

When an airplane is landing, air pressure builds up between the plane and the ground. This "ground effect" pushes back at the plane, and it is a factor in a pilot's handling of the aircraft. Ground effects are fairly well understood for conventional airplanes, but little is known about how they would affect radically different aircraft such as a future supersonic transport.

Researchers at the Langley Research Center are performing tests to understand more about this phenomenon, and they recently performed wind tunnel tests on a Tu-144 planform. The Tu-144 configuration was selected because it has a wing shape similar to that envisioned for the future supersonic transport. The tests generated ground effect data that matched data taken on a Tu-144 flight. These results are significant because they show that wind tunnel tests are a valid means for generating accurate supersonic transport ground effects data. In future work, researchers

Wind tunnel tests prove a valid means for accurate analysis of ground effects on a supersonic airliner configuration, to be correlated with flight test data.

will perform wind tunnel tests to determine the ground effects data of other design configurations. Those data will greatly influence the landing gear design and other requirements for a future supersonic transport.

Peace and Quiet at Mach 2

Researchers in the Tu-144LL flying laboratory collect data to learn how airflow over fuselage generates noise inside the passenger cabin.

Flying at supersonic speeds can get noisy and somewhat uncomfortable for passengers and crew. Interior noise levels on the Concorde, for example, are roughly twice as high as a typical subsonic transport. Because passenger comfort will be very important to the success of future supersonic transports, NASA researchers are addressing the cabin noise challenge. In early 1998, Langley researchers completed noise measurement tests during supersonic flights on the Tu-144LL in Russia. They are currently in the process of analyzing the data collected on the exterior sources that generate noise within the cabin.

Once researchers understand how airflow over the surface of the fuselage generates noise inside the passenger cabin, they can then design an efficient means to reduce the noise level. The results of this research effort will directly impact the design of a future High-Speed Civil Transport and will provide increased comfort for the flying public.

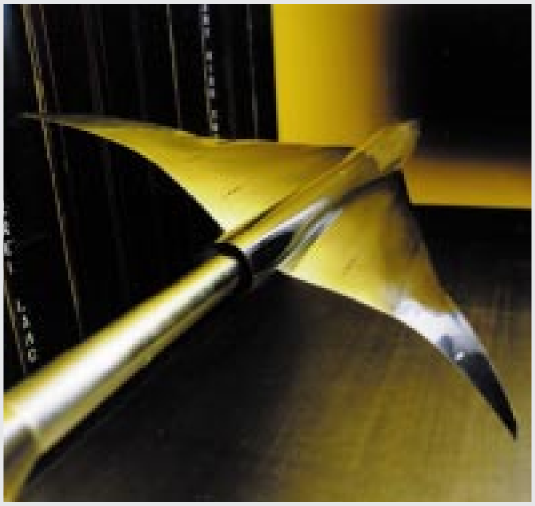
Getting a Handle on Supersonic Flight

Because supersonic airplanes have slender flexible wings and bodies, they are more difficult for pilots to handle than current passenger aircraft. As an example, the automatic flight control system and the pilot's efforts to fly the airplane can sometimes cause undesirable vibration in the cockpit. Minimizing this vibration and improving handling quality are important control system design considerations. To make future supersonic aircraft as easy to fly as possible, NASA researchers are studying ways to suppress the unwanted vibration while allowing the aircraft to respond to the pilot's commands.

In December 1997, a real-time piloted simulation was developed at the Langley Research Center to represent the expected flight and structural dynamics behavior of the aircraft during key mission tasks. This piloted simulation was used to determine requirements for a structural mode control system that will minimize the vibration in the cockpit so that the pilot can perform key tasks. The test results will be used to develop the advanced flight control laws for future supersonic transports. An understanding of these aeroelastic flying qualities and the control criteria will also provide guidance and insight for future designs of other advanced, highly flexible piloted aerospace vehicles.

Test results from a piloted simulation are crucial to making future supersonic aircraft as easy to fly as possible.

Elevating Performance by Lowering Drag



Wind tunnel tests are being used to identify minimum-drag design features.

Langley researchers recently completed supersonic tests in the Unitary Plan Wind Tunnel on a nonlinear design for a supersonic transport. Although the drag reduction measured during the tests was not as great as that predicted using computational methods, significant drag reductions were achieved.

Future tests will be conducted at a higher Reynolds number, which will be more representative of flight conditions. These test results will be used to identify a supersonic transport configuration that provides maximum drag reduction. Reducing drag decreases operating costs by improving fuel consumption and lowering aircraft weight. As a result, this research has the potential to help make a future supersonic transport an affordable means of travel for the flying public.

Big Is Beautiful

For a commercial supersonic airliner to meet the same stringent future noise requirements as subsonic aircraft, a new type of supersonic engine nozzle is being developed and tested in the High Speed Research (HSR) program. The completion of the Large-Scale Model 1 (LSM1) test marks an important first step of the program to test the nozzle design in a realistic engine environment.

Large-scale tests increase confidence that technology goals can be met for quieter supersonic engines.

After extensive research, analysis, and testing, a supersonic inlet was selected for the High Speed Research program.

Before this test, these designs have only been tested in small scale in wind tunnels without the severe operating conditions found behind a jet engine core. These new large-scale technology tests will improve our confidence in the ability of the nozzle to meet the program noise goals.

The LSM 1 test also provided the first opportunity to evaluate new HSR-developed materials required for this nozzle. A noise-quieting liner panel made from a Ceramic Matrix Composite (CMC) material survived testing in the hostile exhaust nozzle environment for 22 hours with no signs of degradation. This test increases confidence that a CMC acoustic liner will be able to meet the 18,000-hour engine life goal.

Engines Breathe Easy at Supersonic Speeds

The inlet to a supersonic engine is critical to the propulsion system. The main purpose of an inlet is to adjust the speed and pressure of air entering the engine, which is essential for efficient performance. When an airplane is traveling at supersonic speeds, the air speed is much higher, making the inlet's function more difficult, and typically more noisy.

A two-dimensional mixed compression inlet configuration was selected after an extensive design study and downselection process. Recent successful tests in the Lewis Research Center's 10x10-Foot Supersonic Wind Tunnel significantly contributed to this selection. This supersonic inlet demonstrated lower weight, lower manufacturing costs, and lower maintenance costs for the same noise level.

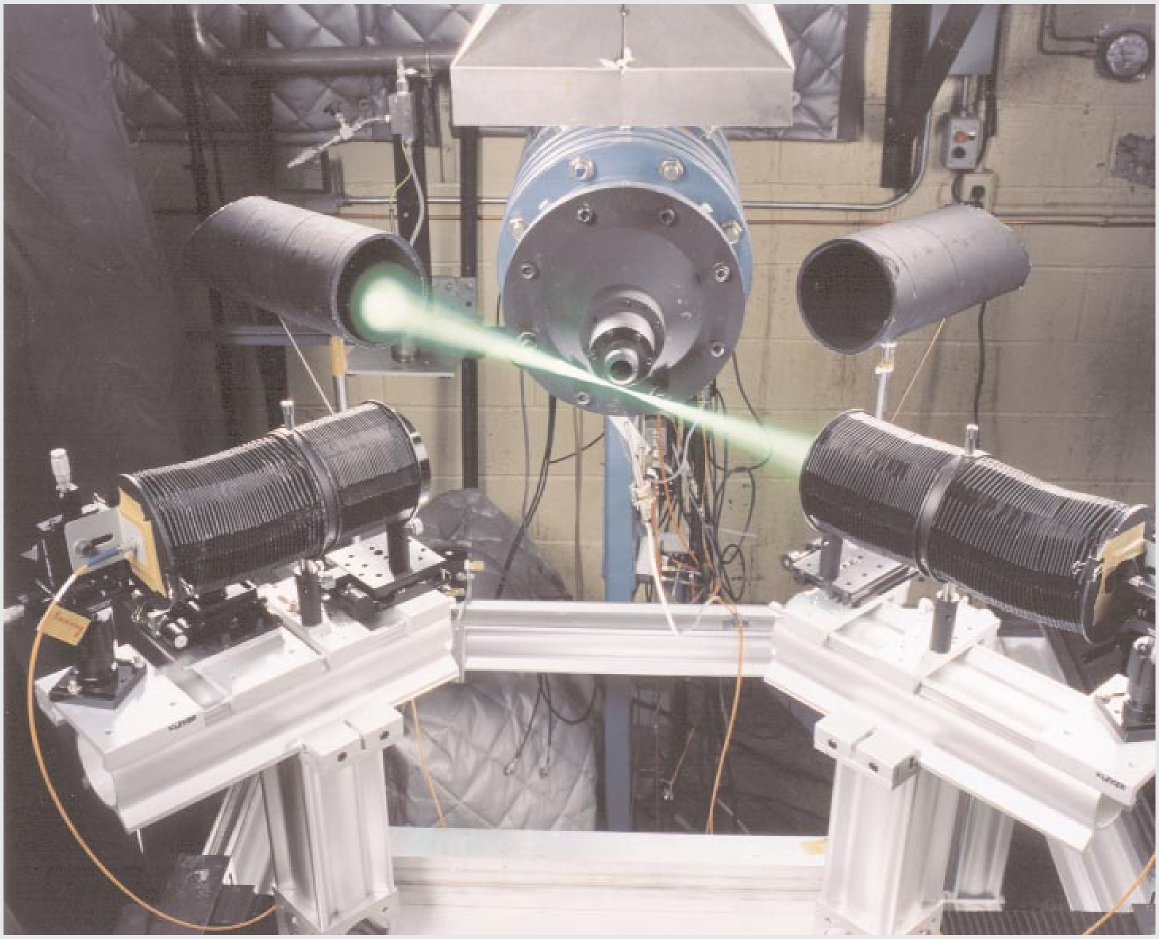
This complex new inlet has the features that are necessary to provide the same high levels of reliability and safety as the simpler inlets currently used in subsonic commercial airliners.

How Can You See Sound?

For the first time, researchers can measure turbulence parameters that will help them understand the physics of how a supersonic jet flow creates sound. Using a laser, optics, and light-collecting instrumentation, researchers can now take measurements without interfering with the flow they are studying.

The technique, called Molecular Rayleigh Scattering, demonstrated the sound generation process through turbulence and shock wave interaction in a shock-containing supersonic jet. The light from an argon-ion laser is transmitted through a multimode optical fiber to test region. The laser light scattered from the molecules in the flow is collected and focused into another multimode optical fiber. The light exiting this fiber is detected with a photomultiplier tube and photon counting electronics. The signal is proportional to the time-varying density of the air. Parameters measured include time-average density, phase-average density, and power spectrum of density fluctuations.

Researchers involved in developing the flow facility, optics, and software to advance this measurement technique acknowledged that the added difficulty of using lasers has paid off by providing very accurate data. The knowledge gained and the accuracy of the data set will enable the development of flow and noise prediction codes. The researchers are looking at further improvements to measure the spectra of velocity and temperature fluctuations in supersonic jets.



A complex new laser measurement technique provides very accurate data for researchers studying supersonic jet flow.

Goal 7: General Aviation

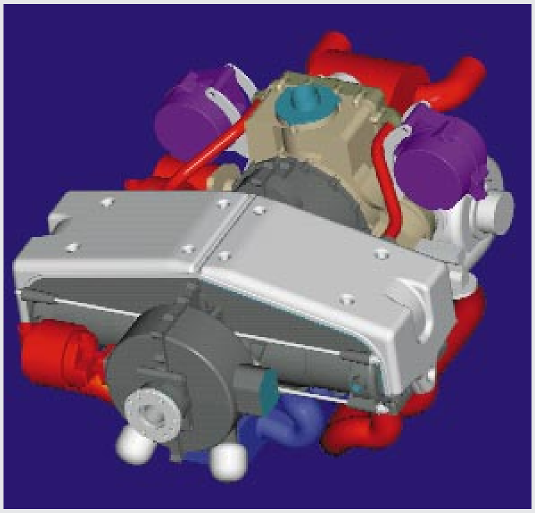
The general aviation segment of air travel, which includes privately owned aircraft, has tremendous potential for growth if a number of technical issues are solved. At its peak in 1978, the U.S. general aviation industry delivered 17,811 aircraft. In 1993, the number of aircraft delivered had fallen to 954, an all-time low. Along with a critical tort reform in 1994, the technology innovations anticipated for general aviation will revolutionize and revitalize this industry. NASA, in cooperation with the U.S. aviation industry and the FAA, has begun two major initiatives—the General Aviation Propulsion (GAP) program and the Advanced General Aviation Transport Experiments (AGATE) consortium—to create the technological basis for this revitalization.

The GAP program is a partnership with industry and the FAA to develop revolutionary, low-cost propulsion systems. Although current engines are good and have served their purpose well, they require a considerable amount of pilot attention, intrude on passenger comfort with noise and vibration, are costly to buy, and have high maintenance requirements. Technology is now on the verge of enabling engines that will provide the same kind of simple (just push on the throttle for power), nonintrusive (smooth and quiet), highly reliable operation that we have come to expect from our automobile engines. The GAP program plans to develop an intermittent combustion engine for entry-level general aviation aircraft and a new turbofan engine for higher performance general aviation aircraft.

The AGATE consortium is a cost sharing partnership with more than 70 members from industry, universities, the FAA, and other Government agencies. It was founded in 1994 to develop affordable new technology as well as the industry standards and certification methods for airframes, cockpits, flight training systems, and airspace infrastructure for next-generation single-pilot, 4–6 place, near all-weather light airplanes.

Enabling Technology Goal: Invigorate the general aviation industry, delivering 10,000 aircraft annually within 10 years, and 20,000 aircraft annually within 25 years.

Radical Engine for Private Aircraft



The newest aircraft piston engine provides very quiet, fuel-efficient, and low-emission operations.

The Lewis Research Center teamed with Teledyne Continental Motors and its industry partners to develop an extremely advanced intermittent combustion piston engine. The first engine has been completed and is now being tested at Teledyne.

The engine incorporates many innovations. It is a horizontally opposed, four-cylinder, liquid-cooled, two-stroke compression ignition (diesel) engine. Compression ignition engines are known to be very efficient and reliable, but they are relatively heavy. With the use of innovative lightweight construction techniques, this engine will produce 200 horsepower with comparable engine weight to current 200-horsepower aircraft engines.

Special design consideration has been given to making this a very quiet and low-emission aircraft piston engine. The engine uses jet fuel instead of leaded gasoline and is about 25 percent more fuel efficient. With its quiet, smooth, and easy-to-use single-lever-power-control operation, a pilot can focus full attention on flying the airplane in a comfortable environment. These vast improvements in engine operation and performance will be achieved even as the engine cost is reduced. The incorporation of unique design features and the development of low-cost manufacturing methods will reduce engine cost by as much as one half.

Cruise Missile Powers V-Jet

NASA has teamed with Williams International and its industry partners to develop a revolutionary new low-cost turbine engine designated the FJX-2. The first FJX-2 will be completed later this year and will undergo testing by Williams International and Lewis engineers.

As a part of its contribution to the GAP program, Williams International also commissioned Scaled Composites to build the V-Jet II aircraft to be a testbed for demonstrating the FJX-2 turbofan engines. This aircraft was flown—and was a major attraction—at the Experimental Aircraft Association's Oshkosh '97 airshow. It was powered by interim FJX-1 turbofan engines, which are modified cruise missile engines.

Modern turbine engines are highly desirable for light aircraft because they are user friendly and environmentally compliant. Their characteristics include very high reliability, smooth operation, and low noise and emissions. However, turbine engines have not been affordable in the light aircraft market. In some cases, turbine engine propulsion systems cost more than the aircraft in which they would be used. Through the unique design, technologies, and manufacturing methods employed in the FJX-2, its cost will be reduced by an order of magnitude over current turbine engines while maintaining performance and usability. With a fan bypass ratio of approximately 4, the FJX-2 will be quiet and fuel efficient. It will produce 700 pounds of thrust while weighing less than 100 pounds.

A low-cost turbofan engine powers the V-Jet II demonstrator aircraft.

Crash-Testing Small Planes

Using several NASA crashworthiness design technologies in test aircraft, the anthropomorphic test dummies "survived" the crash.

In 1997, the Langley Research Center and industry engineers successfully crash-tested a small airplane designed to protect occupants against fatal injuries using airbags, energy-absorbing seats, and a composite materials structure. The program goal was to apply design tool techniques that have been successfully applied in military helicopters, race cars, and modern automobiles to improve survivability in crashes of small composite airplanes. A further goal was to reduce the injury severity in survivable crashes.

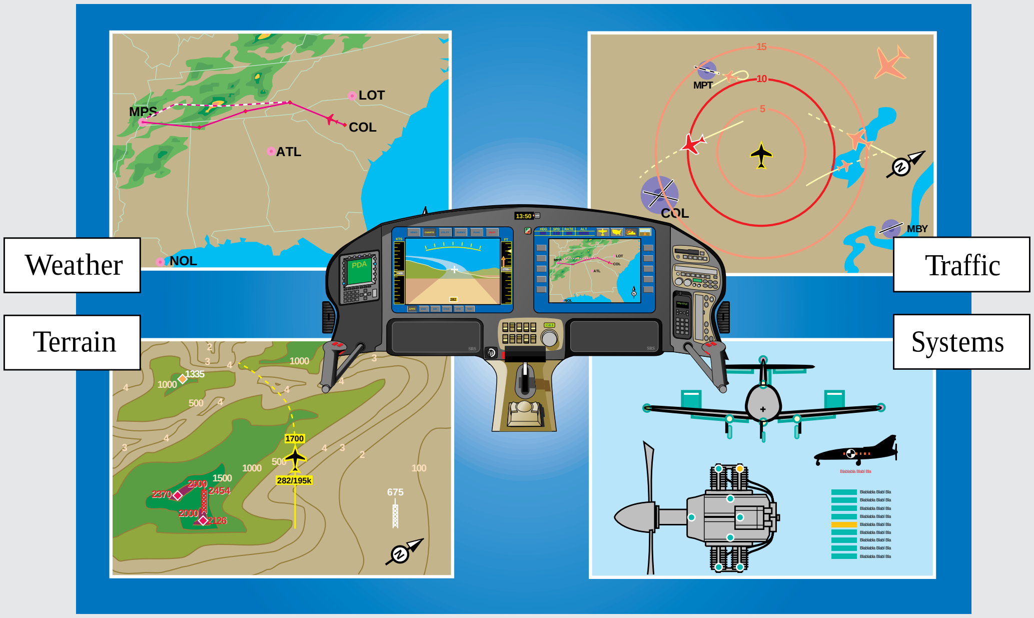
The program used a combination of analysis, subscale quasi-static testing, and full-scale crash testing to achieve these goals. A total of four airplanes were crash-tested over a 2-year period. The tests typically took place at about 60-miles-per-hour impact speed into both earth and hard surfaces. The tests successfully demonstrated an improved shoulder harness system, energy-absorbing seats, and a composite fuselage structure designed for energy absorption, all developed with NASA crashworthiness design technology. In the final crash test, all of the anthropomorphic test dummies "survived" the crash, a first for general aviation crash tests.

Industry is incorporating these safety harnesses, energy-absorbing seats, and composite structures into light planes. As a result, these NASA crashworthiness design technologies will be used to save lives worldwide

The World on Display

NASA and the AGATE Consortium have demonstrated a number of NASA technologies for navigation, weather, terrain, traffic, and system status information. These cockpit systems technologies are being developed by the AGATE Systems Standard Team 1-B (SST-1B), a group of 10 companies, co-led by Rockwell Collins and AvroTec. These experiments have resulted in the first successful combination on a single aircraft of a number of breakthrough technologies, including VHF digital datalink for flight information services and for air traffic control/management communications, automatic dependent surveillance-broadcast air-to-air traffic position reporting, GPS-based attitude heading reference system, "smart chart" GPS-based navigation and terrain guidance, and primary and secondary aviation computers and flat panel displays.

An experimental-certificate Beech Bonanza F33C, owned and modified by Raytheon Aircraft, serves as an "integration platform" testbed for new technologies being developed by the AGATE Consortium. The aircraft also features a unique engineering paint scheme that maps airflow contours over the entire body of the aircraft. This research effort, supported by NASA, the FAA, and more than 70 companies, is directed at revitalizing general aviation by implementing new technologies that make flying safer, faster, more convenient, and more affordable.



This cockpit displays critical status information to the pilot, resulting in improved flight safety.

Goal 8: Design Tools and Experimental Planes

NASA is about opening the air and space frontier. Our heritage of experimental aircraft programs has and continues to push the envelope. Experimental aircraft, or "X-planes," are invaluable tools for exploring new concepts and for complementing and strengthening laboratory research. In the very demanding environment of flight, X-planes are used to test innovative, high-risk concepts, accelerating their development into design and technology applications.

Now we are looking at new tools and technologies that will fundamentally change our engineering culture. In our commitment to cutting cost and cycle time while improving safety and the quality of new products, these tools will change the process of traditional engineering. These will be tools that simulate requirements, design and analyses, prototyping, manufacturing, training, operations, and maintenance to save time and cut costs. The accomplishments here include both flight research and design tool development.

Enabling Technology Goal: Provide next-generation design tools and experimental aircraft to increase design confidence, and cut the development cycle time for aircraft in half.

"DARWIN" Revolutionizes Testing

DARWIN is a NASA computer network tool, developed at the Ames Research Center, that is providing great savings in time and money for airplane makers and the Government by providing faster access to wind tunnel test results. Wind tunnels are chambers through which air flows during tests of aerodynamic shapes. In the tunnels, air is blown around airplane or rocket models to simulate flight. Pressure gauges, strain gauges, and other instruments attached to the models take measurements. Data streaming from the model instruments tell aerospace engineers how much lift, drag, and maneuvering performance an airplane model can generate through different angles of flight and at various speeds, altitudes, and conditions.

DARWIN links wind tunnels to computers that send nearly instant test results via a secure network to geographically separated companies and laboratories. It not only collects test data, but translates them into a usable form for engineers. The system is similar to the Internet but is not open to the public. Its purpose is to get faster results and data from NASA wind tunnels.

Previously, test results had to be derived by scientists and engineers in the days and months following wind tunnel tests. In contrast, DARWIN funnels wind tunnel data into a server computer and then sends preliminary results back to researchers at the test site and elsewhere in the country within about 30 seconds to 5 minutes. Researchers project that this will help reduce the aerospace design cycle time by about 25 percent.

With this capability, engineers can decide earlier in the design cycle if their ideas are working or if the designs must change before expensive prototype airplanes are built (often costing more than $1 million each). Aerospace and computer engineers at Ames continue to develop DARWIN and derivative systems and to integrate them into NASA's system of wind tunnels, which are used extensively by industry to test new airplane concepts. The

Geographically dispersed researchers can now obtain experimental results from NASA's wind tunnels almost immediately.

anticipation is to eliminate inefficiencies, reduce cost, and achieve better designs in less time.

You Can Be There From Anywhere

The Virtual Laboratory enables worldwide teams of researchers to work together on NASA's Vertical Motion Simulator without having to travel.

Until recently, researchers had to be physically present at the world's largest flight simulator, NASA's Vertical Motion Simulator at the Ames Research Center, to conduct their research. With a new portable computerized system, a remote experimenter from practically any place in the world can use a hand controller to "walk around" a three-dimensional, computerized world that represents the simulator and its test facilities.

The Virtual Laboratory, a computerized set of equipment and computer programs, can be shipped to distant companies, universities, and Government test facilities, enabling these remote researchers to participate in simulated test flights. The computer set permits a "tele-researcher" to see a computer animation of test cockpit motions. Moreover, the researcher can see what the test pilot views out of the simulator cockpit. The virtual laboratory and the "world" it creates exist partly in computer memory and partly in physical hardware. The three-dimensional world includes video screens, computer video, two-way videoconferencing, shared whiteboards, remote data access, and the pilot's out-the-window scene.

At the Vertical Motion Simulator, there are five interchangeable cockpits that are used to simulate the Space Shuttle, helicopters, airplanes, and other aerospace vehicles. It is able to move the cockpits in all directions, including 60 feet vertically and 40 feet horizontally. Researchers study aerospace controls, guidance, cockpit displays, automation, and handling qualities of existing or proposed aircraft or other vehicles. The simulator's computers calculate aircraft response when a pilot changes the simulator cockpit controls, in an identical manner to the aircraft in flight.

The Virtual Laboratory can help enable worldwide teams of engineers and researchers work on projects simultaneously without having to travel to the specialized research facilities. NASA engineers have successfully used the portable Virtual Laboratory equipment in Houston to monitor tests at Ames, during which astronauts made simulated Space Shuttle landings with the Virtual Motion Simulator. With the Virtual Laboratory, flight deck designs, training programs, and other aircraft and spacecraft applications and can be developed faster and tested more often to ensure lower cost and greater safety.

New "Power" Tools

In a major milestone for design tools, the Langley Research Center received the delivery of its Aviation System Analysis Capability (ASAC) system from the Logistics Management Institute in McLean, Virginia. ASAC is the first computerized analysis system that uses "intelligent interfaces" to link models and data bases at different geographical sites to enable highly automated analyses and data queries via the Internet. ASAC allows managers to conduct specialized aviation-related analyses, such as community noise impacts, national economic impacts, and safety and operational analyses.

NASA and the aviation industry use ASAC to conduct technology cost-benefit trade studies to guide technology investment strategies for current and future aeronautics programs. ASAC also provides a

NASA's new computer-based analysis tool will be invaluable for assessing the impact of emerging aeronautics technologies on the aviation system.

New capabilities and information technology systems enable wind tunnel testing to be more integral in the aircraft development process.

single focal point linking NASA, the FAA, airlines, and aviation manufacturers together from remote locations, facilitating communication among these aviation-related organizations. It integrates ideally with the up-and-coming Collaborative Engineering Centers. This capability will be invaluable for assessing the impact of emerging aeronautics technologies on the aviation system.

"IT" Will Blow the Competition Away

NASA is working to significantly improve its current methods of wind tunnel testing to increase production and utilization of its existing and future facilities through the 1-year, $35 million Aeronautics Design and Test Environment (ADTE) program. Relying heavily on information technology software and hardware to improve the quality and extent of knowledge extracted from these facilities, the Ames Research Center is working to radically change the role of wind tunnels in the aircraft development process and support increasing demand for wind tunnel testing in the future.

The wind tunnel testing process of the past, which was time consuming and primarily a validation process, will be transformed into a dynamic and integral component in the overall design process. The ADTE program will integrate wind tunnel productivity improvements with technologies such as numerical modeling, manufacturing techniques, instrumentation, and information technologies to make the aircraft design process faster, better, and cheaper.

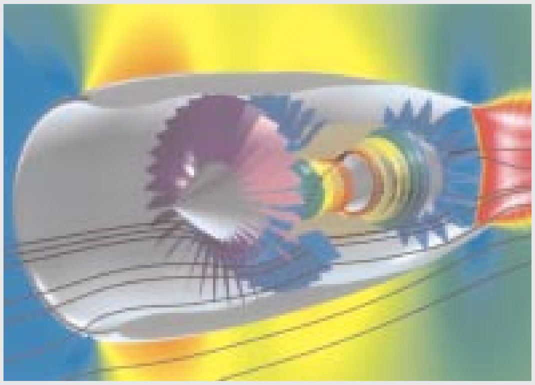
Ames is using its recently rebuilt 12-Foot Pressure Wind Tunnel to install the ADTE prototype systems. A series of tests will be conducted this year to validate these systems and the wind tunnel's capabilities, using four Boeing 777-200 wind tunnel models that were built specifically for these tests.

Because the market drives the economics of aircraft design today, NASA must be responsive to changes. The ADTE program will help change the role of the wind tunnel and contribute toward strengthening the position of United States in the world aircraft market.

Computer Codes Get to the Heart of the Engine

A "full engine" simulation describes how all components of the engine interact. The colors of the blades represent the calculated pressure of the air at that position. The pressure increases as the air flows through the compressor into the combustor (middle section), and it decreases as it expands and exits the exhaust. Typically, computational simulations are performed only on individual components, so they do not capture important interactions between components. These interactions can be critical in the design and analysis of engine performance.

Full engine simulations are being developed to enable designers to understand those complex interactions early in the design process when changes can be made quickly and inexpensively.



The axisymmetric simulation of a full engine, showing pressure-gradient interactions, will be compared to actual engine data to verify accuracy.

The ultimate goal is to go beyond the axisymmetric simulation illustrated in the graphic to a full three-dimensional simulation of the engine. A recent accomplishment toward this goal was to model the aerodynamic interaction between the GE90 engine's 50 blade rows of turbomachinery using a three-dimensional Navier-Stokes analysis. The APNASA (average passage NASA) software code used to perform this simulation was executed on cost-effective workstation clusters. The results gained from the simulation will be compared to experimental data obtained from actual tests run on the GE90 to verify that the code produces accurate results. The code will then be used during the actual design of growth versions of the GE90 engine, which will produce higher thrust up to 115,000 pounds.

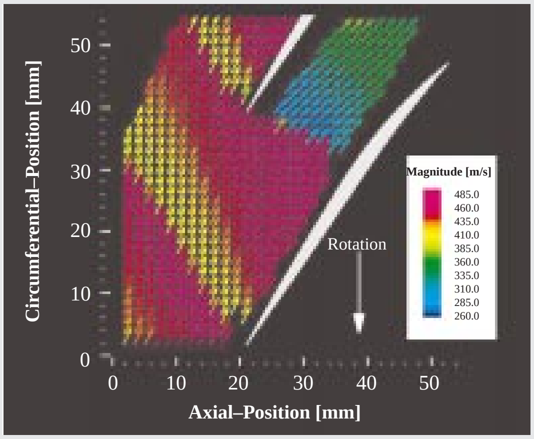
The APNASA software code, developed through a collaborative effort between the Lewis Research Center and General Electric, is an example of a next-generation design tool that will increase design confidence and cut the development cycle time for aircraft in half. Successfully performing this simulation met a major milestone within the High Performance Computing and Communications program's Numerical Propulsion System Simulation (NPSS). The goal of the NPSS program is to perform a full three-dimensional multidisciplinary simulation of an entire aircraft engine in less than a day. The current simulation modeled the aerodynamic properties within the GE90 engine with a simplified combustor. The next milestone in the project will be to model an aircraft engine's performance including chemically reacting, three-dimensional flow in the combustor.

Getting the Big Picture With PIV

Particle Imaging Velocimetry (PIV) is an optical technique whereby a pulsed laser sheet is used to illuminate particles entrained in a fluid across an extended planar cross section of a flow field. Electronic recording of the particle positions at two closely timed laser pulses permits the computation of the flow velocity. PIV captures the instantaneous flow field, permitting the study of unsteady flow phenomena. Mean flow statistics can be computed by acquiring several hundred images and averaging the results.

The first-ever successful application of PIV to acquire measurements in a high-speed rotating turbomachine blade row was completed in the Lewis Research Center's W-8 Single Stage Axial Compressor Facility. Measurements were acquired in a 20-inch-diameter transonic compressor rotor operating at 17,188 rpm. A custom-designed light-sheet-generating probe was used to insert the high-energy, pulsed light-sheet illumination required for recording the unblurred images of particles entrained in the fluid.

Measurements of the shock wave formed within the rotor blade passage, and the unsteady struc-



A measurement technique provides insight into unsteady flow phenomena. Compressor blade rotation is from top to bottom; flow is from left to right. Shock waves are observed off of the blade tips (red-to-yellow transition). A strong normal shock is observed in the blade row throat region (pink-to-blue transition).

tures within the blade wakes were acquired. These measurements provide insight into unsteady spatial structures in the flow field that cannot be measured with the more conventional laser anemometry technique. The PIV technique provides both instantaneous and average velocity data in a transonic compressor in an order-of-magnitude less time than required for other conventional optical diagnostic techniques.

Flying High on Sunlight

The Pathfinder remotely piloted aircraft, which set the world altitude flight record for solar-powered vehicles, is prepared for flight.

The vehicles in NASA's Environmental Research Aircraft and Sensor Technology (ERAST) program are executing their unique mission: "slower, higher, longer."

The ERAST program, led by the Dryden Flight Research Center, aims to develop aeronautical technologies that will lead to a new family of remotely piloted vehicles that will fly: (1) slower—as slow as 15 miles per hour; (2) higher—at altitudes as high as 100,000 feet; and (3) longer—for continuous missions lasting as long as 96 hours.

Between January 1997 and March 1998, the ERAST program achieved several important goals. Most notably, its remotely piloted aircraft, the "Pathfinder," flew to 71,500 feet to set the world altitude flight record for solar-powered vehicles. The flight series that led up to this achievement also verified the aircraft performance modeling, structure, solar array, motors, and flight and thermal controls for very high-altitude, long-endurance solar aircraft.

ERAST also has focused efforts on providing next-generation design tools and experimental aircraft to help increase design confidence and reduce design cycle times for new concepts. The program has achieved a wide array accomplishments, including:

- Validating finite element models and developing structural test techniques for large, flexible wings
- Completing design tool and modeling upgrades to support performance predictions for very high-altitude, long-endurance aircraft powered by internal combustion engines
- Demonstrating the flight performance of a single-stage turbocharged internal combustion engine to an altitude of 43,500 feet
- Operating a remotely piloted aircraft on science missions in FAA-controlled airspace on a shared-use basis
- Demonstrating the utility of long-endurance aircraft as "geostationary" platforms to collect science data in a deployment environment
- Developing and flying new science sensors that are significantly smaller and lighter than their conventional counterparts
- Demonstrating over-the-horizon control of a science payload with nonmilitary space communications equipment

Scramjet Screams at Mach 6.5

The Mach 6.5 Scramjet Flight Research Project is a joint effort between the Central Institute of Aviation Motors in Moscow, Russia, and NASA. A major accomplishment for the program was achieving the world's first fully supersonic combustion mode in flight. The engine involved in this historic flight was launched from Kazakhstan, using an SA-5 rocket booster, and it reached speeds of Mach 6.44.

The world's first fully supersonic combustion mode engine was flown at Mach 6.44.

A scramjet is a supersonic-combustion ramjet. Ramjets operate by subsonic combustion of fuel in a stream of air compressed by the forward speed of the aircraft itself, as opposed to a normal jet engine, in which the compressor section (fan blades) compresses the air. Ramjets operate from about Mach 2 to Mach 5. In a scramjet, designed to operate faster than Mach 5, the airflow throughout the engine remains supersonic. Scramjet technology has applications for both aviation and space access systems.

Tailless Aircraft—The Shape of Things to Come

The NASA Ames/Boeing X-36 Tailless Fighter Agility Research Aircraft successfully completed its flight research program. It demonstrated the feasibility of future tailless fighters achieving agility levels superior to today's best military fighter aircraft. Thirty-one flights were made during the 25-week flight research program at NASA's Dryden Flight Research Center in Edwards, California. The first flight occurred on May 17. The final flight, which closed out the third phase of the program, took place on November 12 and lasted 34 minutes. The X-36 flew a total of 15 hours and 38 minutes and used four different versions of flight control software. The aircraft reached an altitude of 20,200 feet and a maximum angle of attack of 40 degrees.

During the final flight phase, the X-36 project team examined the aircraft's agility at low speed/high angles of attack and at high speed/low angles of attack. The project team also achieved the final flight's goal to expand the X-36's speed envelope up to 206 knots (234 miles per hour). The aircraft's stability and handling qualities were excellent at both ends of the speed envelope.

The X-36 on dry lake bed at the Dryden Flight Research Center is prepared for early morning flight.

The 28-percent-scale X-36, built by the Boeing Phantom Works in St. Louis, Missouri, is designed to fly without the traditional tail surfaces common on most aircraft. The X-36 is 18 feet long with a 10-foot wingspan, is 3 feet high, and weighs 1,270 pounds. The aircraft is powered by a Williams Research F112 turbofan engine that provides 700 pounds of thrust. The aircraft is remotely controlled by a pilot in a ground station cockpit, complete with a head-up display. The pilot-in-the-loop approach eliminates the need for expensive and complex autonomous flight control systems.

Ames and Boeing were full partners in the project, which was jointly funded under a roughly 50-50 cost-sharing arrangement. The combined program cost for the development, fabrication, and flight testing of the two prototype aircraft is approximately $20 million.

Passive Porosity a Dynamic Success

Wing drop is an abrupt, uncommanded rolling motion of the aircraft during certain flight conditions. Although not a safety-of-flight issue, the rolloffs occur during high-speed maneuvers and prevent the pilot from performing close-in tracking maneuvers on potential adversaries. Having identified wing drop as a problem in early 1996, a Boeing-Navy team performed wind tunnel tests and computational fluid dynamic studies in an effort to identify the root cause. The results indicated that the problem was associated with airflow separation differences between the left and right wings. Although the cause of the wing drop was clear, knowing how to control and prevent it was not.

In the fall of 1997, the Navy asked the Langley Research Center to assist in solving the problem, which was a growing concern during flight tests. This joint team of engineers proposed a wide variety of solutions. During this period, Langley engineers suggested that the flight program apply a NASA-developed technology—passive porosity—to a small section of the upper surface of the wing at the point where the wing folds up for aircraft carrier operations. In the end, Boeing used a direct application of NASA technology to resolve the “wing drop” phenomenon. The application was optimized as a team effort by NASA, Boeing, and the Navy, and the resolution of the problem permitted the Navy to authorize a low-rate initial production of the aircraft.

The Navy asked an independent group of experts to review efforts to resolve the F/A-18E/F wing drop problem. Based on the group’s recommendations, Langley has proposed a project intended to rectify this national shortcoming in understanding, predicting, and alleviating the abrupt wing stall at transonic maneuver conditions. This research will be applicable to the F/A-18E/F configuration, as well as to other high-performance military aircraft concepts.

A solution to the “wing drop” phenomenon permitted the Navy to authorize a low-rate initial production of the F/A-18 E/F aircraft.

Twisting Wings for Better Performance

The F-18 wing was modified (inset) to increase its flexibility for control of the wing shape during flight.

Dryden’s Active Aeroelastic Wing (AAW) program, in cooperation with the U.S. Air Force Research Laboratory at Wright-Patterson Air Force Base in Ohio and Boeing Phantom Works in St. Louis, Missouri, is researching technology that uses active leading-edge and trailing-edge control surfaces to warp an aircraft’s wing. A preliminary design of AAW wing modifications and flight control software and hardware have been completed.

The program’s goal is to harness wing deformation to provide large control forces at high speeds. The wing deformation is done by blending structures and flight controls technologies, using traditional aircraft control surfaces such as ailerons and leading-edge flaps.

The benefits of implementing AAW technologies will be to increase roll control at high speeds and increase wing life by controlling the loads. This will result in a significant reduction in wing structural weight without reducing the wing’s strength.

Dryden’s F/A-18 840 will be used as the testbed for demonstrating the AAW technologies. The AAW flight research program will change the design paradigm for wing structures by making wings that are lighter and more aerodynamically efficient. As a result, aircraft designs will change toward configurations with longer, thinner wings and without horizontal tails, dramatically reducing drag and improving maneuvering performance.

Speed—Crossing the Line From Super to Hyper

This joint effort of NASA's Langley Research Center and Dryden Flight Research Center will flight-test, for the first time, research vehicles powered by airframe-integrated, dual-mode supersonic-combustion ramjet (scramjet) engines at Mach 7 and 10. In early 1997, contracts were awarded for the final design and fabrication of three Hyper-X Research Vehicles (HXRV) and three Hyper-X Launch Vehicles (HXLV). Fabrication began in September 1997, and the first major program deliverable, the Mach 7 engine, will arrive at Langley for wind tunnel tests in 1998.

Significant NASA technical contributions to date include the scramjet flow path design, the detailed structural design for the Mach 7 scramjet engine, the research vehicle, engine and stage separation control laws, and the aerodynamic and loads data base. More than 1,200 wind tunnel tests of a dozen models have been conducted in support of the aerodynamic, propulsion, and stage separation data base development for risk reduction and design method validation. In addition, extensive computational fluid dynamics support has been provided, and NASA researchers are working to solve challenging Hyper-X design issues, such as the upgrades to the Mach 7 HXRV required to ensure its survival at Mach 10. Both wind tunnel and computational work continues to support this program.

In 1997, updated design tools were applied with the goal of significantly improving scramjet engine performance. The outcome was verified through experimental tests, achieving the best scramjet performance to date in wind tunnel testing. In addition, three-dimensional thermal analysis tools were developed, the primary analysis tool to predict lift and pitching moments was improved, and a NASA force accounting system for hypersonic vehicles was developed. These technology contributions will reduce overall program risk and reduce the design cycle time for future hypersonic systems.

Extensive scramjet engine testing will be performed in Langley's 8-Foot High Temperature Tunnel in late 1998 and early 1999. The Mach 7 HXRV will be delivered to Dryden in May 1999 and the Mach 7 HXLV in September 1999. The first Mach 7 flight, which will be launched from the Dryden B-52, will be in January 2000. The flights, when coupled with the ground-based research, will demonstrate airframe-integrated scramjet performance in flight. This effort will significantly advance the state of the art, acquiring crucial data unavailable in ground tests and validating key technologies and design methods that would enable creating air-breathing aerospace planes for hypersonic cruise and space access.

Hundreds of Hyper-X wind tunnel tests were conducted to build data bases for validating design methods and reducing the risk of this cutting-edge technology program.

Pillar Three: Advanced Space Transportation

Our experience with the vast resource of space has already yielded new treasures of scientific knowledge, life-enhancing applications for use on Earth, and fantastic celestial discoveries. The potential for the future seems almost limitless, but we must begin now if we are to succeed in realizing the benefits that leadership in this endeavor will bring.

NASA envisions successive but overlapping efforts to dramatically reduce costs and increase the reliability of space transportation. First, America must finally achieve affordable access to low-Earth orbit. But getting to low-Earth orbit is only part of the picture; we must then achieve affordable orbital transfer through low-cost, reusable upper stages. And finally, we must continue to open space for human endeavor through innovative, low-cost transportation solutions for missions beyond Earth's orbit. Entrepreneurs, scientists, students, explorers, and many others will then be active participants in an exciting era of space development.

Goal 9: Low-Cost Space Access

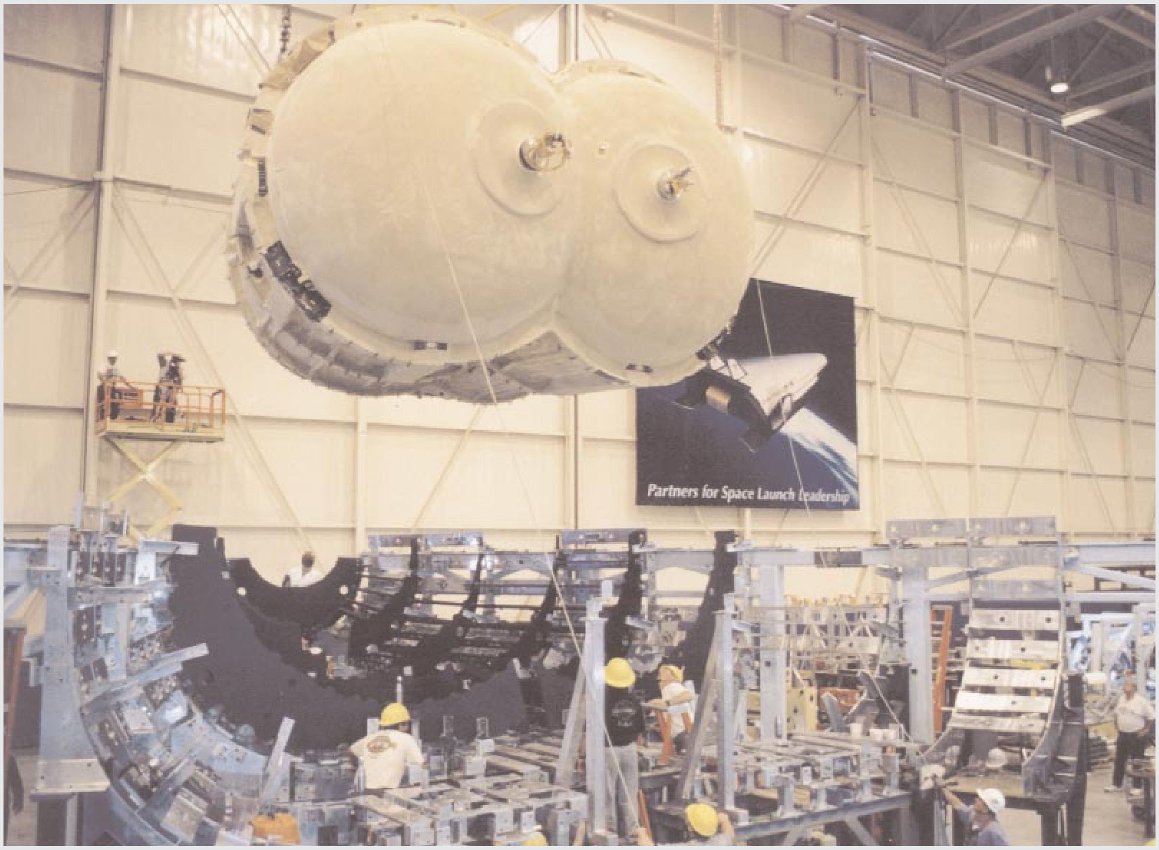
The X-33 and X-34 programs were designed to pave the way to a full-scale, commercially developed reusable launch vehicle. The X-33 is the flagship technology demonstrator for technologies that would dramatically lower the cost of access to space. It is unpiloted, taking off vertically like a rocket, reaching an altitude of up to 60 miles and speeds in excess of Mach 13 (13 times the speed of sound), and landing horizontally like an airplane. As many as 15 test flights are planned, beginning in late 1999.

The X-34 is a reusable, suborbital, air-launched vehicle that will fly at speeds approaching Mach 8, or eight times the speed of sound, at altitudes up to 50 miles. It will demonstrate several key technologies, bridging the gap between the subsonic Clipper Graham DC-XA flights in 1996 and the larger and higher performance X-33 demonstrator. Beginning in 1999, up to 25 flights are scheduled to occur within a year's time, launching and landing within the airspace of White Sands Missile Range, New Mexico. The X-34 will also fly in Florida to demonstrate subsonic landing and thermal protection system performance in inclement weather conditions. With such fast-paced schedules to develop and flight-test the prototypes, the year has been filled with milestones.

Enabling Technology Goal: Reduce the payload cost to low-Earth orbit by an order of magnitude, from $10,000 to $1,000 per pound, within 10 years, and by an additional order of magnitude within 25 years.

The Start of Something Big

In April 1998, the X-33's first major flight component, the liquid oxygen tank, was placed in the

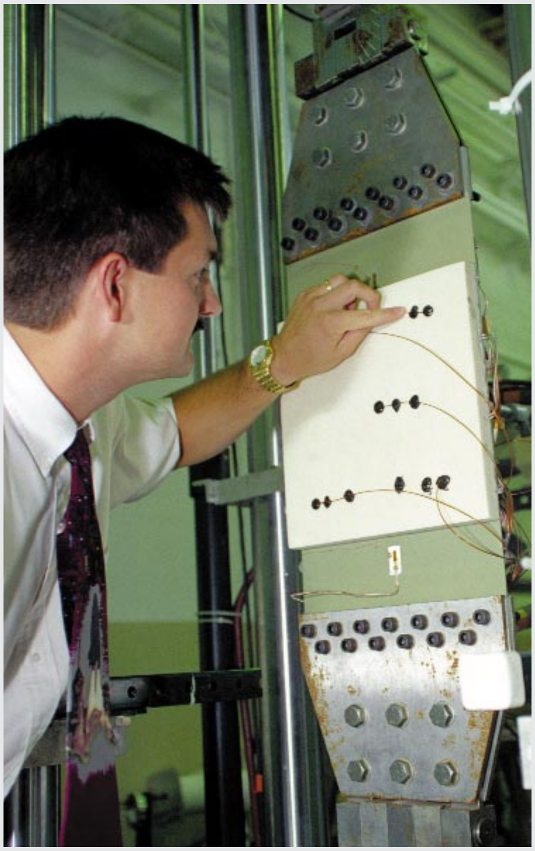


The 26-foot-long, 5,500-pound aluminum liquid oxygen tank is lowered into the X-33's primary assembly structure.

vehicle's assembly structure. Crews flawlessly performed the hour-long process as the enormous tank was placed within a cradle of composite ribs—called the "stand-off structure"—that will provide the separation between the tank and the outer thermal protection system, which will be integrated into the assembly structure in later months.

The huge liquid oxygen tank had arrived by air at the assembly facility in Palmdale, California, just 2 months earlier. The tank was assembled by one of the many industry partners supporting this trail-blazing program, Lockheed Martin Michoud Space Systems in New Orleans. Its integration into the assembly structure marked the start of an ambitious schedule that calls for the X-33 vehicle to roll out and begin flight tests in the summer of 1999—just 36 months from the program's inception.

From Fire to Ice, Materials Must Perform



Researcher conducts tests on a sample of insulation material for the cryogenic fuel tank.

In 1997, researchers at the Langley Research Center conducted thermal-mechanical tests of candidate X-33 cryogenic fuel tank insulation systems. One of the greatest challenges of designing the fuel tank insulation system is finding the right material to withstand the extremely low temperatures. The tests were used to verify that advanced insulation systems would indeed withstand the temperatures and forces experienced during launch, orbit, and reentry.

To simulate the heat of reentry, a panel covered with cryogenic foam insulation was heated to temperatures above those expected during a reentry. The panel was also subjected to design loads that simulated the launch-to-orbit and a reentry, and at the same time, simulated cooling/heating cycles were applied. To verify the durability of the systems, the tests were then repeated to simulate the projected number of missions the vehicle will fly. Data from the tests were used to determine the size, design, and performance of the cryogenic insulation system for the X-33. The tests demonstrated the viability of new and innovative cryogenic tank insulation concepts at relatively low cost.

At the end of 1998, structural tests of full-scale panels representative of the X-33 cryogenic hydrogen tank walls will be tested in the Langley Cryogenic Pressure Box (CPB) facility. The CPB facility was designed and built over the past 2 years to provide a capability to test cryogenic tank structural concepts in realistic environments at much lower cost than existing test facilities. The CPB facility can test the structural performance of panels with sizes up to 5 feet by 6 feet, over temperatures ranging from room temperature to –423 degrees Fahrenheit on the inside wall and room temperature to 1,000 degrees Fahrenheit on the outside wall.

Squeezing More Fuel Into a Tank

Technology to create supercooled liquid hydrogen and liquid oxygen propellant is a key means to lowering launch costs. Densified propellants enable more to be packed into a given volume, thus improving the launch vehicle's performance. Researchers at the Lewis Research Center are

Technicians at NASA's Plum Brook Station in Sandusky, Ohio, work on a proof-of-concept fuel densification system.

developing a continuous propellant densification concept for reusable launch vehicles that takes a much simpler and more cost-effective approach over the technology developed in the early 1980's to create slush hydrogen. The work at Lewis will demonstrate the feasibility of loading and maintaining densified propellants on an operational launch vehicle.

Vehicle designers and mission planners would like to take advantage of the fact that propellants at temperatures below their normal boiling point have a higher bulk density and reduced vapor pressure. The greater density fluid permits the use of smaller sized and consequently lighter launch vehicle propellant tanks. The lower vapor pressure allows the vehicle tank design and operating pressure to be reduced, permitting the use of thinner walled vessels. All of this results in a vehicle with a lower dry mass, increased propellant loading, and higher performance.

Lewis is on track to begin assembly of larger liquid oxygen and liquid hydrogen densifiers this summer. Because of the size of the units—about 1,000 cubic feet each—the hangar will be used as the assembly and checkout facility. When completed next spring, the hardware will be shipped to the Marshall Space Flight Center and the Stennis Space Center for further testing. This propellant is being baselined into Lockheed Martin's reusable launch vehicle concept, which the company has named VentureStar™.

New Wave Ignition

A novel system that dramatically simplifies the ignition of rocket engines with large numbers of combustors is readied for testing.

The Lewis Research Center, in cooperation with Boeing's Rocketdyne Division has been testing a novel rocket engine ignition system, called the Combustion-Wave Ignition System. The system is unique in that it largely simplifies ignition in rocket engines with a large number of combustors. The particular system tested has been designed for the X-33, with two aerospike rocket engines each containing an enormous number (20) of combustors.

The goal of the tests is to verify that the system design is sound and to clearly define its flight operational procedure. The test program has, thus far, collected information from a subscale prototype, and it is now working on a full-scale model. The program continues to identify the design and operational characteristics of the ignition system, generating the data base and gaining experience useful for the system's future applications.

Hot-Fire Tests of Revolutionary Engine

The linear aerospike engine, which will power the X-33 test vehicle, undergoes the hot-fire test of components.

In April 1997, the Marshall Space Flight Center completed a series of hot-fire tests on components for the X-33's linear aerospike engines. Engineers tested three side-by-side thrust cells and a small section of the revolutionary engine's nozzle, or ramp, to provide designers with data on cell-to-cell interaction, the engine's unique plume, and the temperatures experienced by the spike-shaped ramp, which for the X-33 is constructed of a copper alloy.

The tests illustrated the expertise and infrastructure NASA can provide to industry. With this test series, Marshall's engineers and test stands allowed the Center to provide valuable information to the X-33 engines' builder, Boeing's Rocketdyne Division.

World's Fastest Laboratory

NASA's SR-71 with the linear aerospike experiment mounted between the two vertical tails conducts airborne ignition tests.

Linear aerospike rocket engines have been laboratory- and ground-tested many times over the past 30 years, but have never been flown until now. The goal of this SR-71 flight experiment program is to gather data on the exhaust plume of the linear aerospike engine at transonic speeds (approximately 750 miles per hour).

In March 1998, the experiment achieved its first in-flight "cold flow" (cycling of nitrogen and helium through the engine without ignition), followed in April 1998 by its first airborne ignition test. The experiment hardware consists of a scale model of the X-33 containing an aerospike engine and a housing that contains the gaseous hydrogen, helium, and instrumentation gear. The entire experiment package, which is 41 feet in length and weighs 14,300 pounds, is mounted on the back of NASA's SR-71A.

In a "typical" test flight, the SR-71A will rendezvous after takeoff with a tanker aircraft for aerial refueling. The aircraft then climbs to a predetermined altitude between 20,000 and 80,000 feet and accelerates to the desired test speed. The aerospike engine is then fired to collect inflight data on the engine's performance. There is enough fuel for one aerospike rocket engine firing per test flight, and each firing lasts 2 to 3 seconds. The flight program covers a range of test conditions from subsonic speeds up to Mach 1.5.

Tools of the Trade

NASA researchers observe results of a computational analysis for the X-33 vehicle's aerodynamic flow and engine plume.

The Marshall Space Flight Center, the Langley Research Center, and the Air Force's Arnold Engineering Development Center conducted numerous wind tunnel tests of various-sized models of the X-33 to refine the vehicle's design and define its stability and control characteristics across its operational speed range. To maintain the fast pace of the program, NASA also broke new ground in the area of vehicle design with its extensive use of computational fluid dynamics—the analytical prediction of a fluid's behavior. Langley's computer-driven design analysis complemented the wind tunnel testing and allowed designers to quickly determine the effects of changes to the vehicle's configuration.

Langley wind tunnel tests determined aerodynamic characteristics over the X-33's complete flight envelope, from hypersonic to subsonic, including ground effects on the vehicle during landing. These aerodynamic data are extremely significant because they are used to design the flight control system for the vehicle. Hypersonic aerodynamic heating effects were also identified. In addition, extensive configuration development testing was performed to determine the appropriate body shape, fins, and body flaps to enable the vehicle to fly at hypersonic speeds. These tests, and others, contributed to the selection of the final vehicle configuration, determination of the expected vehicle surface temperatures in flight, and definition of the thermal protection system for the vehicle.

Progress From Around the Nation

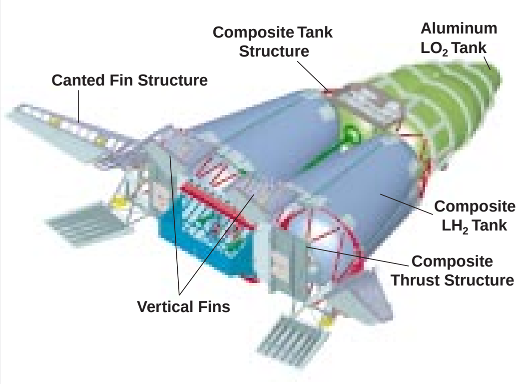
This F-15B carries an experiment to evaluate the performance of X-33 metallic thermal protection tiles during high-speed suborbital flight.

Extensive test and development were conducted programwide as industry partners tackled the bulk of their work on components and subsystems that will make the X-33 a reality. Alliant Techsystems began fabrication of the X-33's two multilobed, composite liquid hydrogen tanks. One of the enormous tanks began the curing process in a Lockheed Martin facility in Sunnyvale, California, in April 1998, and both tanks are scheduled to be flown to the Marshall Space Flight Center later this year for extensive testing.

Meanwhile, Aerojet in Sacramento, California, continued its work on the vehicle's reaction control system, conducting numerous hot fires for the eight thrusters that will help control the X-33's pitch and yaw at high altitudes. AlliedSignal in Teterboro, New Jersey, continued to refine its software for the vehicle's autonomous flight system, and Sanders in Nashua, New Hampshire, continued to refine the integrated vehicle health monitoring system, which will track the status and structural integrity of its components. The health monitoring system also plays a large role in enabling ground crews to quickly and accurately assess the vehicle's condition and work toward airline-like turnaround times.

B.F. Goodrich (formerly Rohr) in Chula Vista, California, continued producing and testing with NASA the rugged metallic thermal protection tiles that will be used to protect the X-33 from the high temperatures it will encounter as it passes through the upper atmosphere. A flightweight metallic thermal protection panel array has been successfully tested in the Langley 8-Foot High Temperature Tunnel. Also, Boeing Rocketdyne in Canoga Park, California, continued its development of the X-33's linear aerospike engines, conducting component tests with NASA and producing flight components for later assembly into the revolutionary engines.

All Systems—Go

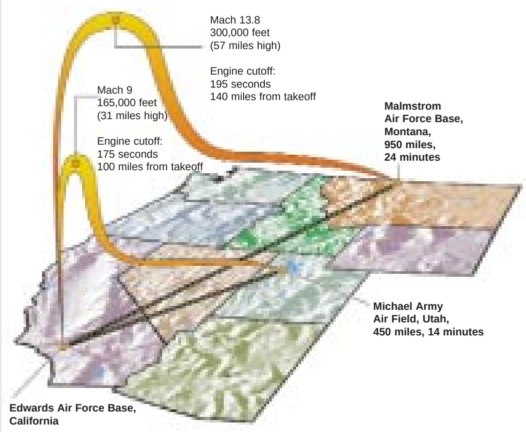


Detailed design of the X-33 technology demonstrator.

Notably, along with their development and testing efforts, all of the industry partners with NASA completed the subsystem and component critical design reviews during 1997. Those 51 design reviews culminated in a comprehensive critical design review of the X-33 program in October 1997. Approximately 600 representatives from NASA, industry team lead Lockheed Martin, industry partners, and the U.S. Air Force participated in the 5-day review held at Edwards Air Force Base, California.

The review gave the program a vote of confidence and the go-ahead for the fabrication of all remaining components and the completion of subsystems and assembly of the vehicle. The review also served as an opportunity for program officials to announce the resolution of issues that arose earlier that year regarding vehicle weight and aerodynamic stability and control. The X-33 team's weight reduction efforts and modifications to the design of the vehicle's canted and vertical fins paved the way for a successful review and a successful program.

Meeting Environmental Standards



Alternative X-33 flight paths and landing sites considered in the Environmental Impact Statement.

The critical design review was quickly followed by another major success for the program, the completion of the X-33 Environmental Impact Statement in November 1997. The year-long environmental process looked at issues surrounding the X-33's flight test program. It consisted of 21 public meetings in six States, extensive public involvement and support, and a multifaceted team of environmental experts working to complete a more than 1,000-page environmental report. The report considered issues such as public safety, noise, impacts on general aviation, and effects on biological, natural, and other resources at two proposed takeoff sites on Edwards Air Force Base, five proposed landing sites, and the overland flight corridors. The findings of the study supported the X-33 program's preferred flight test plan.

Initial flights will go to Michael Army Air Field at Dugway Proving Ground, Utah, approximately 450 miles from Edwards Air Force Base. Longer flights of about 950 miles will go to Malmstrom Air Force Base, Montana, to more extensively test the X-33's performance and thermal protection systems. A flight to Dugway will have a duration of 14 minutes at a top speed between Mach 9 and 11. The flight to Malmstrom Air Force Base will run 24 minutes at a top speed between Mach 13 and 15.

Launching From Haystack

The $30 million launch facility at Edwards Air Force Base will be completed in the fall of 1998.

The completion of the environmental impact statement paved the way for construction to begin on the X-33's launch site at Edwards Air Force Base. In November 1997, representatives from NASA, the U.S. Air Force, and industry broke ground at the 25-acre launch site located in the eastern portion of Edwards, a few hundred yards north of what is known as Haystack Butte. All 15 planned test flights of the X-33 are scheduled to be launched from the Edwards facility beginning in 1999. Approximately 100 workers will construct the $30 million launch facility, with work scheduled to be completed in the fall of 1998. Industry partner Sverdrup Corporation of St. Louis, Missouri, is overseeing the facility's construction.

Site plans include a retractable vehicle shelter, a rotating vehicle launch mount, storage areas for the liquid hydrogen and liquid oxygen used for fuel and the helium and liquid nitrogen used in vehicle operations, a water storage tank for the sound suppression system, a concrete flame trench, and assorted site infrastructure. The vehicle's operations control center will be located in an existing test control room within Haystack Butte.

Bearing up Under Stress

Wingbox structure being subjected to load-testing that simulates conditions a reusable launch vehicle would experience in flight.

The Langley Research Center completed the first structural tests of full-scale components of a reusable launch vehicle. The tests were designed to validate structural design techniques for composite primary structures, which would be used on a reusable launch vehicle. The use of composites for the primary structures, such as the wings and intertank, is essential for a cost-effective launch system that can also meet the weight requirements for a single-stage-to-orbit vehicle.

Two components, a wing box and intertank structure, were subjected to loads simulating what a reusable launch vehicle would experience during launch, entry, and landing. The components were tested to failure to ensure strength and performance of the structures. The wing box broke at twice the design load limit. The intertank segment of fuselage failed at a lower load than expected.

Knowing at what load and how a structural component fails is essential to being able to design a vehicle that will be safe at all expected flight conditions. These test results validated the design, fabrication, and analysis tools needed for the development of the Nation's next-generation reusable launch vehicles. The composite wing box was selected by *Aerospace Engineering Magazine* as one of the top 15 technologies for 1997.

More Than a Data Point

A 1/30-scale X-34 model is tested in Langley's Unitary Plan Wind Tunnel to determine supersonic aerodynamic characteristics.

Wind tunnel testing of the X-34 vehicle is almost finished. Thus far, the Langley Research Center has delivered five versions of the aerodynamic data base derived from more than 1,000 hours of wind tunnel testing. They will complete the data base during the fall of 1998. The tests are an accurate indicator of how the vehicle will perform in different flight modes and speeds up to eight times the speed of sound, as well as how it will fly and land. Langley—NASA's center of excellence for aeroscience—is a partner with Orbital Sciences Corporation, industry's prime contractor for the vehicle. Additional Langley work on the X-34 includes aerodynamics, structures, materials, and vehicle systems analysis.

A Dress Rehearsal

Fuselage skin panel assembly for the X-34 was completed in October 1997. Orbital Sciences Corporation built a full-scale vehicle to verify the design and structural integrity of the vehicle with low-cost composite skin panels. The pathfinder is identical to a flight vehicle, except it uses inexpensive simulators for internal components, such as avionics, propellant tanks, and the main propulsion system. The X-34 team expects a significant savings by testing the fuselage, or shell of the vehicle, with simulators to verify that the systems are operational before flying the more expensive, fully outfitted flight vehicle. Plans also call for testing the vehicle's guidance navigation system and landing capabilities in an unpowered mode by dropping the pathfinder from a plane and letting it glide to the landing strip at White Sands in New Mexico.

Workers at Orbital Sciences Corporation in Dulles, Virginia, work on the covered frame for the X-34 vehicle.

Flying With an Attitude

The Flush AirData System's performance for the X-34 is validated on the Systems Research Aircraft.

The Systems Research Aircraft at the Dryden Flight Research Center successfully validated an air data system that will be used aboard reusable launch vehicle technology demonstrators such as the X-33 and X-34, to indicate the attitude of the vehicle during flight. In supporting the Flush AirData System (FADS) development for the X-34, Dryden provided the port design layout and FADS software development and checkout. Dryden's X-34 project team also completed environmental laboratory qualification and acceptance of FADS pressure transducers. Dryden procured and delivered a laboratory test version and two flight-qualified FADS flight control computers to Orbital Sciences Corporation for the X-34 flight vehicles.

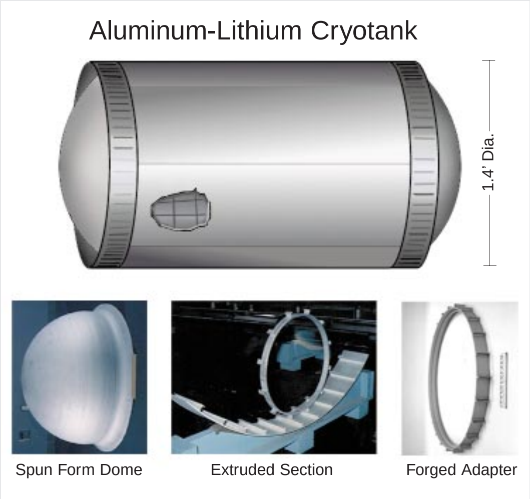
This air data system could also be used on other revolutionary vehicles, such as the X-38 crew return vehicle prototype and the Hyper-X hypersonic experimental vehicle.

Giving Launchers a Lift

Flight research demonstrated the feasibility of using large aircraft to tow a launch vehicle to launch altitudes and speed.

The Eclipse Program supported Kelly Space & Technology Inc.'s plan to finance and construct a commercial space launch vehicle called the Astroliner. All three of the Eclipse's objectives were successfully accomplished. The objectives were to demonstrate towed takeoff, climb-out, and separation of the EXD-01 from the towing aircraft; validation of simulation models of the towed aircraft systems; and development of ground and flight procedures for towing and launching a delta-winged airplane configuration safely behind a transport-type aircraft.

Shaving Costs Without Machining



"Near-net-shape" manufacturing techniques are being applied to the construction of advanced cryogenic fuel tanks.

Technology advances for manufacturing cryogenic tanks are needed to reduce the cost as well as increase the reliability of future space transportation vehicles. The goal of NASA's Cryogenic Tank Technology program, which began in 1990, is to develop the technology advancements that will result in lighter and less expensive propellant tanks.

The Langley Research Center, in partnership with the Marshall Space Flight Center and Lockheed Martin, has developed a new process for manufacturing cryogenic fuel tanks with aluminum-lithium (Al-Li) alloys. Al-Li alloys are lighter than traditional tank materials and have the potential to reduce the weight of a tank by 20 percent, thereby reducing the overall cost and increasing the performance of the cryogenic tank system.

Cryogenic fuel tanks such as those currently used for the Space Shuttle external tank are made with traditional fabrication methods that involve an expensive machining process, which results in 80 to 90 percent of the raw material being scrapped. The new process can reduce the material scrap rate to 20 percent.

The new technology is referred to as "near-net-shape" manufacturing. The cryogenic tank barrel sections are made from integrally stiffened extrusions (that is, manufactured with stiffeners and skin in a single piece). Near-net roll-forged structural elements and spun-formed domes are also incorporated into the tank. The components are then joined together to form the cryogenic tank using friction stir welding, a new solid-state welding process.

This manufacturing process has the potential to enhance the properties of the structure, resulting in stronger and more reliable tanks, which is important for reusability. The fabrication of the first cryogenic tank is scheduled to be completed in 1999, at which time it will be ready for structural testing.

Radical Reentry Research

Ames Research Center engineers have developed a new thermal protection system material designed to prevent spacecraft from burning up during reentry into the Earth's atmosphere. The development and testing of the new material are part of a joint program among NASA, Sandia National Laboratories, and the U.S. Air Force, called Slender Hypervelocity Aerothermodynamic Research Probes (SHARP).

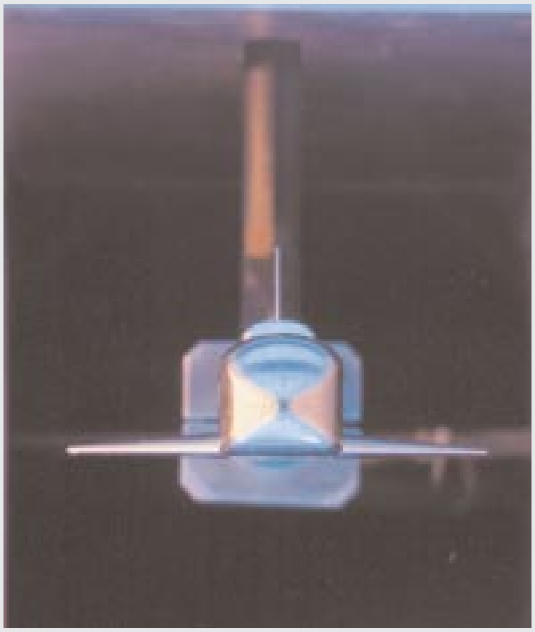
The objective is to demonstrate the viability of sharp leading edges for space vehicles. The new material performed extremely well during its first flight test in May 1997. Plans for additional flights are currently under discussion. If subsequent tests are successful, the potential of this ultrahigh temperature ceramic material to support the use of hypersonic sharp leading edges will revolutionize the approach that engineers take in designing and protecting spacecraft and transatmospheric vehicles.

The sharp-body designs offer reduced drag, thereby providing substantial savings in the cost per pound expended to put objects into orbit. They also provide a greatly enhanced lift-to-drag ratio, enabling what is called cross-range capability, for a spacecraft or transatmospheric vehicle to reenter the Earth's atmosphere from any orbit and land at any location, unlike present blunt-body vehicles. Finally, sharp leading edges minimize the number of free electrons that interfere with radio frequency transmissions and cause the communications blackout associated with the reentry of blunt-body vehicles.

New thermal protection materials, being tested on cone-shaped probes, have promise for revolutionizing spacecraft design by providing a new approach to reentry.

The ultrahigh temperature ceramic material that just completed its first flight test was already proven in ground-based testing in the Ames arcjet facilities. The material was very stable at temperatures in the range of 1,700 to 2,800 degrees Celsius (3,092 to 5,072 degrees Fahrenheit) in the presence of high-velocity dissociated air, such as is encountered during conditions of reentry. The material is resistant to thermal shock and fatigue failure and, hence, is reliable for repetitive operation and use over multimission life cycles.

Rocketplane



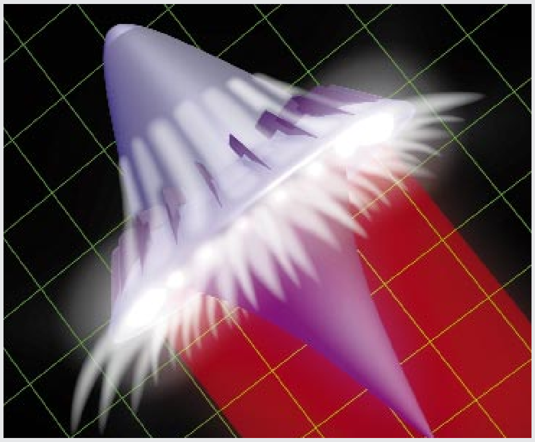
Testing of a Pioneer Rocketplane subscale model in a supersonic wind tunnel.

The Pioneer Rocketplane concept consists of an airplane-like vehicle that incorporates both jet engines and a rocket engine to deliver small payloads to low-Earth orbit for a fraction of today's costs. A unique feature of this concept is that the liquid oxygen propellant for the rocket phase of the mission is transferred into the vehicle at altitude, from a tanker aircraft.

Pioneer Rocketplane was one of four companies awarded contracts by the Marshall Space Flight Center in fiscal year 1997 to pursue low-cost "bantam-class" reusable launch vehicle concepts. The Lewis Research Center performed wind tunnel testing of a pathfinder model in its 1x1-Foot Supersonic Wind Tunnel during December 1997 and January 1998. The test results will be used by Pioneer Rocketplane to help optimize the vehicle design and attitude control system.

The bantam lifter concept vehicle model, 1/100 scale, was mounted on a remotely actuated sting/strut mechanism that penetrated the facility ceiling. Pneumatic boots provided a conformal, air-tight seal around the strut throughout the penetration zone. This sealed actuation system reduced the required test time by two orders of magnitude. The test data consisted of surface static pressures and Schlieren photographs of the model for discrete vehicle attitudes (pitch or yaw) over a wide range of supersonic Mach numbers.

Launching on a Laser Beam



Artist's concept of launching rockets with laser beam technology.

A futuristic concept of launching rockets to space on laser beams is being demonstrated in ground testing. Testing indicates that laser propulsion may be a viable way to reduce the cost of getting to space. In November 1997, researchers launched the first outdoor free flight of a laser-powered vehicle. A tiny, 6-inch, 2-ounce aluminum model soared more than 50 feet during initial outdoor tests conducted at White Sands Missile Range in New Mexico and soared more than 85 feet in April 1998 tests.

The experiment works by shining a laser beam on a reflector, located at the rear of the vehicle, which acts as a concentrator. Air is heated rapidly and blasted out the back of the nozzle to propel the vehicle. That process is repeated at the rate of five cycles per second.

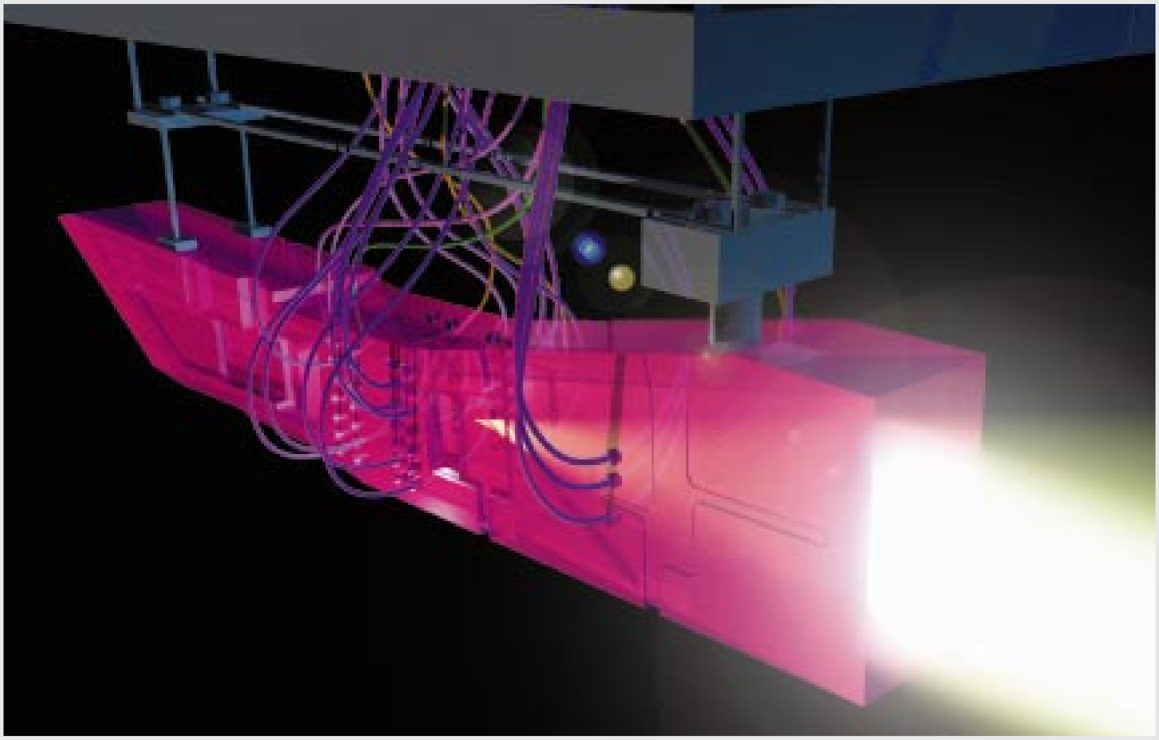
The laser propulsion research is a joint effort of the Marshall Space Flight Center's Advanced Space Transportation Program, the Air Force Research Laboratory's Propulsion Directorate at Edwards Air Force Base, California, and Rensselaer Polytechnic Institute in Troy, New York.

Air Boosts Rocket Performance

Looking farther into the future, the Advanced Space Transportation Program is developing technologies to enable routine access to space. One of the new technologies under development is a rocket engine that consumes oxygen in the air for about half the flight. Today's rocket engines consume stored oxidizer exclusively, which makes the vehicle very heavy at liftoff. An air-augmented rocket engine would mean significant savings because much of the propellant that usually loads a vehicle would not be required.

In January 1998, an air-augmented rocket was tested in the supersonic combustion mode at Mach 8—flowing air through the engine at eight times the speed of sound. The successful testing at Mach 8 came less than a month after engineers first tested an air-augmented rocket at Mach 6 in both the supersonic-combustion (scramjet) and subsonic-combustion (ramjet) modes. In the ramjet and scramjet modes, the air-augmented engine's rockets rely totally on oxygen in the air to burn hydrogen fuel. While the aerospace industry has previously conducted scramjet tests as high as Mach 15, this marks the first test demonstration of a simulated air-augmented rocket engine operating as high as Mach 8. Ground testing in the scramjet mode is being conducted at facilities at General Applied Sciences Laboratory in Ronkonkoma, New York.

A 9-month series of more than 180 tests on a rocket thruster for the air-augmented engine ended in March 1998 at the Marshall Space Flight Center. NASA engineers conducted extensive testing to measure the thruster's performance with different chamber pressures and fuel mixtures before integrating the thrusters into the engine. The rocket thrusters will provide most of the launch vehicle's speed at both takeoff and the final stage that pushes the vehicle into orbit. Air-augmented propulsion will provide the vehicle speed during the middle phase of flight. NASA and its industry partners plan to build a flight-type engine and complete ground testing by 2001. A flight demonstration is planned for 2002.



Artist's concept of an air-augmented rocket being test-fired.

Goal 10: In-Space Transportation

While enabling low-cost Earth-to-orbit transportation (Goal 9) is a critical first step, over 70 percent of all payloads need transportation beyond low-Earth orbit. In-space transportation systems of the future will feature simpler, lighter weight, low-maintenance vehicles that may use alternative energy sources. From solar propulsion to antimatter, the Advanced Space Transportation Program is experimenting with innovative technologies that could transform science fiction into scientific fact.

Enabling Technology Goal: Reduce the cost of interorbital transfer by an order of magnitude within 15 years, and reduce travel time for planetary missions by a factor of two within 15 years, and by an order of magnitude within 25 years.

Harnessing the Sun's Heat

A system that could revolutionize space propulsion is tested in NASA's X-ray Calibration Facility.

NASA's Advanced Space Transportation Program is experimenting with ways to harness the Sun's energy to propel vehicles through space. A solar thermal propulsion system that could significantly reduce weight, complexity, and cost, while boosting performance over current conventional upper stages, was tested in October 1997 in Marshall's X-Ray Calibration Facility.

The technology development project—known as Shooting Star—features a 6-foot-wide, thin-film lens supported by an inflatable frame. The concentrator assembly is designed to focus the Sun's rays into an engine that could reach temperatures of 3,000 to 5,000 degrees Fahrenheit with no combustion or moving parts. Tests were conducted in a stainless steel vacuum chamber—the heart of the X-Ray Calibration Facility—to help researchers evaluate how the solar thermal propulsion system will operate under extreme temperature conditions and with vibration and pressure changes.

A New Era Begins

Ion propulsion technology will debut in October 1998 as the primary propulsion source for Deep Space 1—a mission designed to validate technologies for 21st century spacecraft.

The ion propulsion (or solar electric) engine, which measures approximately 12 inches in diameter, was developed at the Lewis Research Center. It generates thrust by accelerating electrically charged xenon atoms at speeds topping 68,000 miles per hour. The thrust produced is equivalent to the pressure of a single sheet of paper held in the palm of the hand. Although very small when compared to the thrust from chemical systems typically used for on-board propulsion, it produces the thrust for thousands of hours, enabling spacecraft to travel far distances at increasing speeds. Ion propulsion will increase the speed of Deep Space 1 by 7,900 miles per hour over the course of the mission.

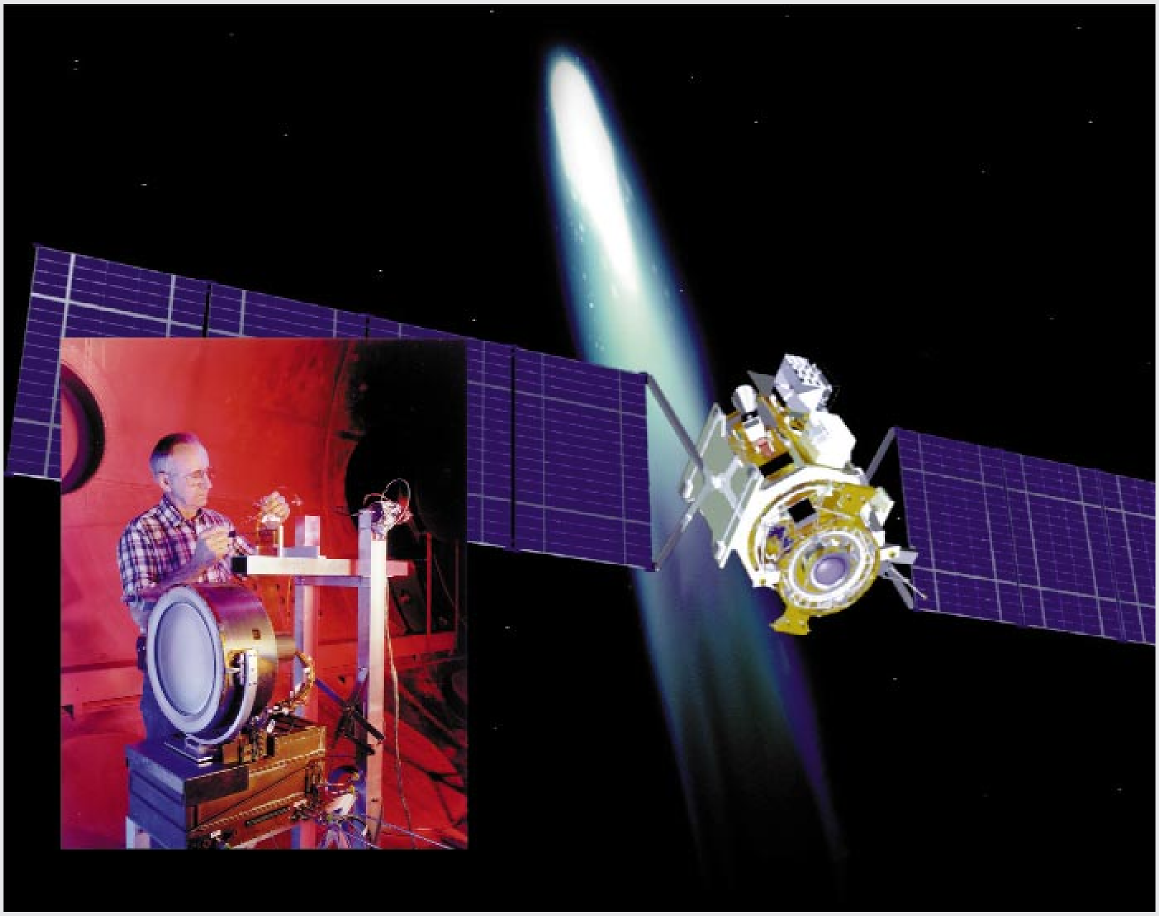
Although the ion engine was first built and tested in 1959, it was not until 1992 that it was considered for a space mission when the Lewis Research Center and the Jet Propulsion Laboratory (JPL) in Pasadena, California, began developing flight hardware for Deep Space 1.

Lewis researchers developed a prototype ion engine and a power-processing unit to convert energy captured by the solar arrays on Deep Space 1 into 2,300 watts of power for the engine. An 8,000-hour, full-power endurance test was conducted from June 1996 to September 1997 inside a JPL vacuum chamber. It verified that the engine and its systems have what it takes for long missions. Hughes Electron Dynamics Division, Torrance, California, has been selected to build the first flight engines, power processors, and controllers.

Deep Space 1 is NASA's first mission to be flown under the New Millennium program. This program is designed to reduce the risk of using revolutionary technologies in future interplanetary missions by taking aggressive risks in smaller, faster, and cheaper technology validation missions.

Deep Space 1 will test 12 advanced technologies and instruments. In addition to ion propulsion, the mission will validate an autonomous optical navigation system, a solar power concentrator array, and an integrated camera and imaging spectrometer. This 2-year mission, under the NASA Solar Electric Propulsion Technology Applications Readiness (NSTAR) project, includes a flyby of Mars, an asteroid, and a comet. The flight will be carried out jointly by JPL and Spectrum Astro, Inc., of Gilbert, Arizona.

As Deep Space 1 breaks free of Earth's gravity, it will usher in a new chapter in the history of space exploration. Two weeks after the Delta upper stage gives the spacecraft its final push, the ion engine will kick into full gear.



The NSTAR ion thruster, undergoing preliminary testing (inset), will power the Deep Space 1 satellite.

Goal 1: Aviation Safety

Goal 2: Emissions Reduction

Goal 3: Noise Reduction

Goal 4: Aviation System Capacity

Goal 5: Affordable Air Travel

Goal 6: High-Speed Travel

Goal 7: General Aviation

Goal 8: Design Tools and Experimental Planes

Goal 9: Low-Cost Space Access

Goal 10: In-Space Transportation

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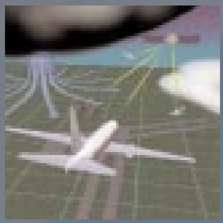

Pillar One
Global Civil Aviation

Pillar Two
Revolutionary Technology Leaps

Pillar Three
Access to Space

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